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U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY—Bulletin No. 51.

D. E. SALMON, D. V. M., Chief of Bureau.

THE AVAILABLE ENERGY OF TIMOTHY HAY.

INVESTIGATIONS WITH THE RESPIRATION CALORIMETER,

IN COOPERATION WITH

THE PENNSYLVANIA STATE COLLEGE AGRICULTURAL
EXPERIMENT STATION.

BY

HENRY PRENTISS ARMSBY, Ph. D., and J. AUGUST FRIES, B. S.



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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY,
Washington, D. C., September 10, 1903.

SIR: I have the honor to transmit herewith a manuscript dealing with "The available energy of timothy hay." This work comprises the records of a careful and difficult experiment which has been carried on by Dr. H. P. Armsby and J. August Fries at the Pennsylvania Agricultural Experiment Station, in cooperation with this Bureau. I recommend that this manuscript be published as Bulletin No. 51 of the series of this Bureau.

Respectfully,

D. E. SALMON,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

STATE COLLEGE, PENN., *August 10, 1903.*

SIR: I have the honor to submit herewith a report upon the first series of experiments with the respiration calorimeter constructed at The Pennsylvania State College Agricultural Experiment Station by the cooperation of that station and the Bureau of Animal Industry of the United States Department of Agriculture. The apparatus is modeled after the one devised by Professors Atwater and Rosa, of Wesleyan University, Middletown, Conn., for investigations upon human nutrition, with such modifications as were necessary to adapt it to experiments with domestic animals. Special acknowledgment is due Professor Atwater and his associates for freely placing at our disposal the results of the experience gained in the construction of their apparatus and for many valuable suggestions as to improvements.

This first series of experiments with a new and complicated apparatus was much more successful than might have been anticipated. While the results in some directions require the confirmation of further experiments, they open up interesting lines of investigation, while they possess a certain interest as being, so far as we are aware, the first actual determinations of the heat production of an agricultural animal, and we therefore feel justified in presenting them as a report of progress. As the consequence of an entire recomputation, the figures here reported differ somewhat from those contained in the preliminary account of the experiments contained in the Proceedings of the Society for the Promotion of Agricultural Science for 1902.

The details of the experiments, especially of the determinations with the respiration calorimeter, have been in the hands of Mr. Fries, to whose untiring labors the larger share of their success is due. Acknowledgment should also be made of the skill and faithfulness of our assistants, Messrs. C. W. Norris, J. B. Robb, T. M. Carpenter, and N. W. Buckhout, in the execution of the laborious respiration and calorimetric experiments, and of the cooperation of the chemical division of the station, under the direction of Dr. William Frear, in

the examination of feeds and excreta, Dr. C. A. Browne, jr., having had general charge of the reception and care of samples, and having executed the determinations of carbon and hydrogen, while the determinations of heats of combustion have been made by Mr. Norris. The weighing and sampling of feed and excreta were skillfully performed by Mr. A. K. Risser, who also had charge of the records of the digestion work.

Very respectfully,

HENRY PRENTISS ARMSBY,
Expert in Animal Nutrition.

D. E. SALMON, D. V. M.,
Chief of Bureau of Animal Industry.

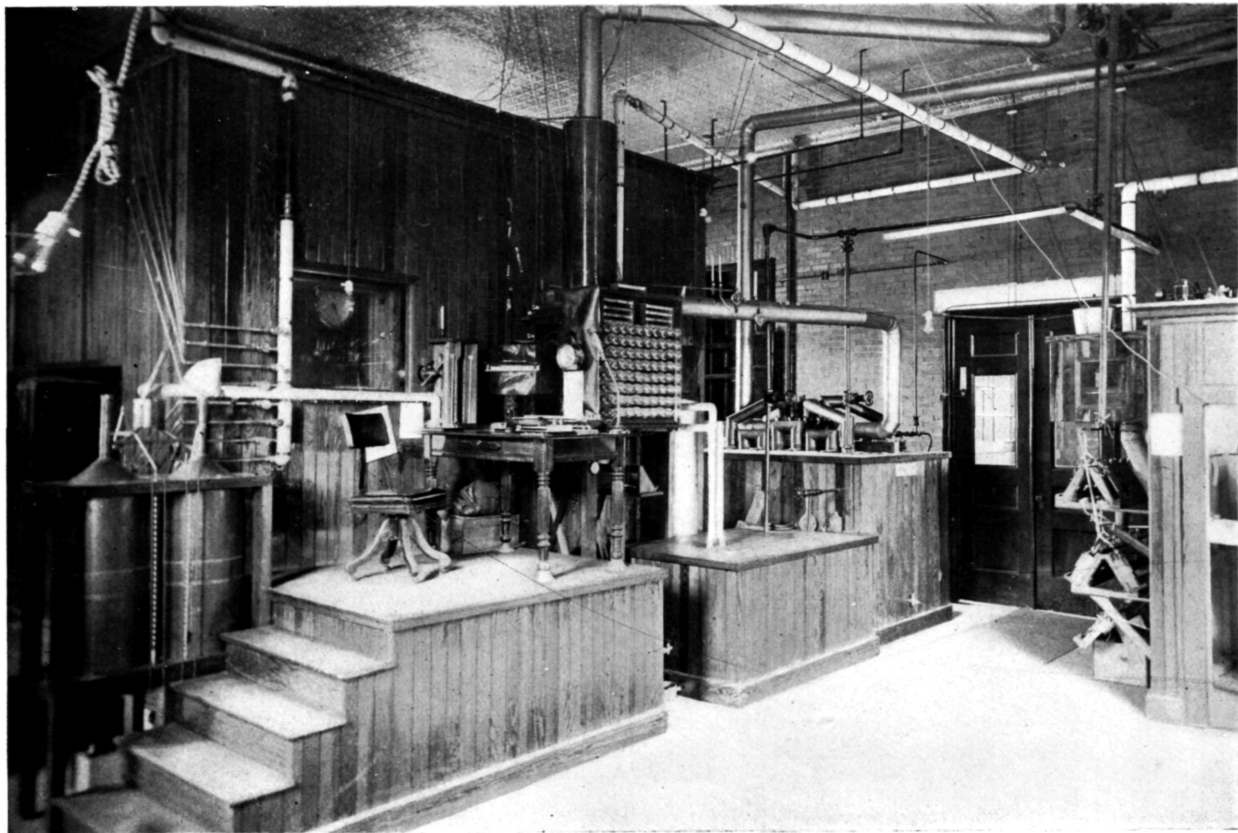
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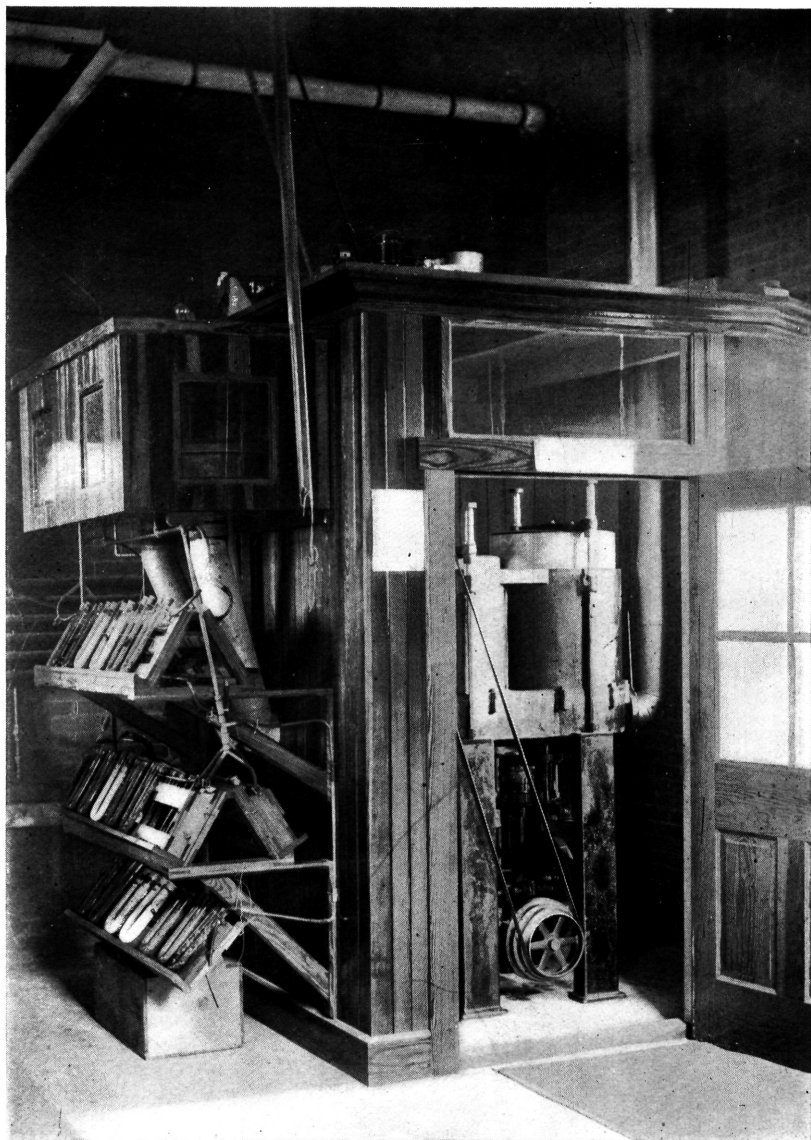
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THE RESPIRATION CALORIMETER.



THE METER PUMP AND ABSORPTION TUBES.

THE AVAILABLE ENERGY OF TIMOTHY HAY.

By HENRY PRENTISS ARMSBY, Ph. D., and J. AUGUST FRIES, B. S.

INTRODUCTORY.

The available energy of a feeding stuff in the narrower sense may be defined as the amount of energy which it is capable of contributing to the maintenance of the store of potential energy contained in the tissues of the animal. The simplest method of determining available energy, and one which has been extensively used in experiments upon carnivorous animals, consists in comparing the fasting metabolism of the animal with that upon a known amount of the food in question. The extent to which the loss of energy by the fasting animal is diminished by the consumption of the food affords a measure of its available energy in this sense. With herbivorous animals, for obvious reasons, it is impracticable to use the fasting state as a basis of comparison, since even when deprived of food the resorption of matter from the alimentary canal would undoubtedly continue for a considerable time. The comparison can be equally well made, however, with the metabolism upon a basal ration to which known quantities of the material in question are added. This method of experimentation has been extensively employed by Kellner in his determinations of the productive value of feeding stuffs and has been used in this investigation.

Timothy hay was selected as the subject of investigation as constituting a fairly definite farm product and also because of the somewhat greater simplicity of experiments with coarse fodder alone. This was an advantage which, however, had to be sacrificed later on account of the poverty of the hay in protein, linseed meal being added to supply the lack. Starting with a basal ration of hay and a small amount (400 grams per day) of linseed meal, the total ration being considerably below the maintenance requirement, three different amounts of the hay experimented upon were added in as many periods and the balance of carbon, nitrogen, and energy determined in each period.

It was originally intended to make the experiment upon two animals, but, owing to the limited time available for the work and the difficulty of selecting suitable animals, one only was finally used (No. 1). This animal was purchased in the Pittsburg market in the fall of 1900. At the time of the experiment it was about 3 years old. The breeding of the animal was unknown, but it apparently contained more or less Shorthorn blood.

DESCRIPTION OF THE EXPERIMENT.**ANALYTICAL METHODS.**

The analytical methods employed for the analysis of the feed and excreta were substantially those recommended by the Association of Official Agricultural Chemists. Pentosans were determined by Kröber's modification of Tollens and Krüger's method.^a The nitrogen of the feces was determined in the fresh material by König's method and the nitrogen of the urine by direct oxidation by the Kjeldahl method. In the computation of proteids from proteid nitrogen, Ritthausens factor 5.5 was used for the linseed meal and the conventional factor 6.25 for the timothy hay. The nonproteids were computed from the nonproteid nitrogen by multiplication by 4.7, the factor for asparagin. The pepsin-insoluble nitrogen of food and feces was determined by the method of G. Kühn.^b The ordinary analytical methods were employed for the determination of carbon and hydrogen. The heats of combustion of the food and excreta were determined by means of the Atwater-Hempel bomb calorimeter.

THE FEEDS.

Hay.—The hay used was well-cured timothy, grown on the station farm in the summer of 1901. It was cut July 2 and housed July 3. About 2 tons of this hay were run through a feed cutter on November 8, 1901. The machine used was one which employs a blast of air to deliver the cut material, and the result of this was that the lighter parts of the hay were blown out and practically lost, leaving a residue of rather inferior composition. The mass of cut hay was twice thoroughly mixed with shovels on the barn floor and then spread out evenly in a mass about 2 feet deep. A narrow ditch was cut diagonally through the mass, the cut hay being removed and carefully subsampled. A second ditch was then cut through on the opposite diagonal and a separate subsample taken from this hay. The subsamples were chopped fairly fine in a meat chopper, and a sample of about 4 or 5 kilograms of the chopped hay taken to the laboratory. These samples were air dried, coarsely ground while still warm, and again subsampled. In these last two samples the composition of the dry matter and its heat of combustion were determined. During the progress of the experiment a sample of hay was also taken at the time of weighing out for each period, or four samples in all. The close agreement of the results upon all these samples, as shown in the following table, demonstrates the substantial accuracy of the sampling:

^a Jour. f. Landw., v. 48, p. 357.

^b Landw. Vers. Stat., v. 44, p. 188.

Composition of hay (dry matter).

Constituents and energy.	General samples.			Samples taken during experiments.			
	A.	B.	Average.	Period 1 (B).	Period 2 (C).	Period 3 (A).	Period 4 (D).
Ash .....per cent..	4.36	4.91	4.64	4.55	4.60	4.63	4.67
Proteids .....do....	5.34	5.36	5.35	4.79	4.72	4.74	5.37
Nonproteids .....do....				.20	.17	.26	.32
Crude fiber .....do....	39.57	38.20	38.92	38.50	38.50	38.62	38.81
Nitrogen-free extract .....do....	48.79	49.31	49.01	49.67	49.84	49.58	48.26
Ether extract .....do....	1.94	2.22	2.08	2.29	2.17	2.17	2.57
	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Pentosans .....do....	23.92	24.07	24.00				
Total carbon .....do....				46.71	46.19	46.45	46.53
Total nitrogen .....do....	.854	.858	.856	.809	.792	.814	.926
Proteid nitrogen .....do....	.777	.760	.769	.767	.756	.758	.858
Heat of combustion, Calories per gram	4.549	4.558	4.554	4.595	4.551	4.527	4.556

Linseed meal.—The comparative poverty of the hay in protein, as shown by the above figures, together with the results of a preliminary digestion experiment, which revealed a low percentage digestibility of the protein and a material loss of nitrogenous tissue by the animal, showed that it would be necessary to add some proteid material to the basal ration. New-process linseed meal was selected for this purpose. One hundred pounds of the meal were thoroughly mixed and set aside especially for this experiment. The four samples taken during the several periods showed the composition given in the following table, the agreement of the results being very satisfactory:

Composition of linseed meal (dry matter).

Constituents and energy.	Period 1 (B).	Period 2 (C).	Period 3 (A).	Period 4 (D).
Ash .....per cent..	5.26	5.41	5.35	5.36
Proteids .....do....	31.18	30.56	31.17	30.36
Nonproteids .....do....	2.60	2.59	2.46	3.12
Crude fiber .....do....	8.69	9.25	8.92	9.21
Nitrogen-free extract .....do....	42.08	42.12	41.87	41.65
Ether extract .....do....	10.19	10.07	10.23	10.30
	100.00	100.00	100.00	100.00
Total carbon .....per cent..	48.12	48.43	48.20	48.71
Total nitrogen .....do....	6.223	6.107	6.190	6.184
Proteid nitrogen .....do....	5.668	5.556	5.667	5.520
Heat of combustion .....Calories per gram..	5.106	5.094	5.097	5.111

PERIODS AND RATIONS.

During the latter part of October and through November, 1901, the two steers were fed approximately a maintenance ration of uncut hay. Beginning November 30, a digestion trial upon the timothy hay alone was carried out with both steers, the preliminary feeding extending from November 30 to December 9, inclusive, and the digestion period proper, during which the excreta were collected, from December 10 to 19, inclusive.

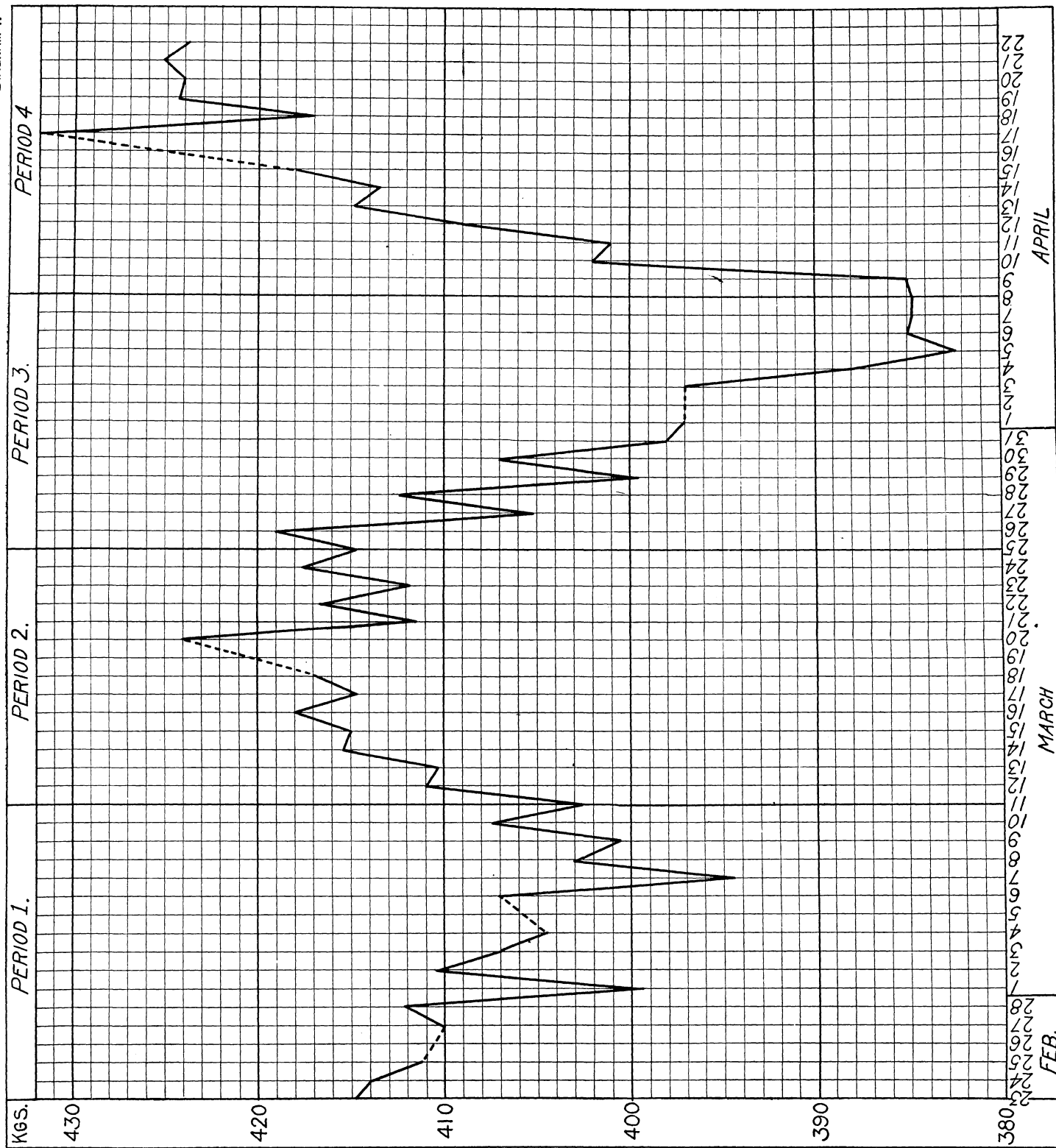
Following this digestion period, steer No. 1 was fed daily about 15 pounds of uncut hay until February 22, 1902, when the experiment proper began. At that date the animal was taken from the barn to the calorimeter building and the feeding with the experimental rations begun. The following table shows the dates of the several periods and the rations fed. During the first period the preliminary feeding covered ten days, and the succeeding digestion period seven days. The subsequent periods were of two weeks each, the first week being regarded as preliminary. It will be noted that the smallest ration was fed in the third period. As a matter of convenience in discussion, the several periods have also been designated by letters, and in the following discussion of the results they are referred to by these letters and considered in the order of magnitude of the rations:

Dates and rations.

Period—		Date.		Ration.	
No.	Letter.	Preliminary period.	Digestion period.	Timothy hay.	Linseed meal.
				<i>Kilograms.</i>	<i>Kilogram.</i>
1	B	Feb. 23–Mar. 4.....	Mar. 5–11.....	4.531	0.400
2	C	Mar. 12–18.....	Mar. 19–25.....	5.750	.400
3	A	Mar. 26–Apr. 1.....	Apr. 2–8.....	3.250	.400
4	D	Apr. 9–15.....	Apr. 16–22.....	7.000	.400

LIVE WEIGHTS.

During the feeding in the barn, including the preliminary digestion experiment, the animal was weighed daily at 1 p. m., immediately before watering, and also immediately after, the difference being taken as representing the amount of water consumed. During the experiment proper the same hours were observed with the exception of the days when the animal was in the respiration calorimeter, in which case the weight was taken immediately before entering and immediately after leaving the apparatus. The figures for live weight and amount of water consumed are given in Table I of the Appendix in connection with the weights of the excreta, and are also shown graphically on Diagram I.



DIGESTIBILITY OF THE RATIONS.

WEIGHING AND SAMPLING OF THE FEED.

Hay.—The hay, both in the preliminary digestion trial and in the several periods of the experiment proper, was weighed out in advance in cloth bags, a day's ration in a bag. In filling the bags the mass of hay was worked into from the side, taking all the material down to the floor. While the bags were being filled two or three large handfuls of the hay were taken from each bag and set aside in a covered vessel. Immediately after the weighing this sample was chopped in a meat chopper, thoroughly mixed, and a sample of 1,000 to 1,500 grams taken immediately to the laboratory in a covered vessel for determination of dry matter and of the composition of the latter, with the results shown in the table on page 11.

Linseed meal.—The linseed meal required was also weighed out in advance for each period in glass fruit jars which were sealed and kept in a cool place until used. At the time of weighing out a sample of 300 or 400 grams was drawn and taken immediately to the laboratory for determination of dry matter and its several ingredients, with the results shown in the table on page 11.

Feeding.—In the preliminary digestion trial the day was regarded as beginning at 1 p. m. In the experiment proper 6 p. m. was taken as the beginning of the day as a matter of convenience in arranging for the work with the respiration calorimeter. Approximately one-half of the hay and linseed meal was given at this time and the remainder twelve hours later. Both were fed dry, the linseed meal being simply scattered over the hay.

Treatment of samples.—The samples, upon being received at the laboratory, were immediately weighed, air dried at a temperature of about 60° C., allowed to hang at ordinary temperature in heavy paper bags for several days, and then ground in a mill as rapidly as practicable, and preserved in sealed, glass-stoppered bottles. The analyses were made as promptly as practicable, although not in all cases immediately.

COLLECTION AND SAMPLING OF THE EXCRETA.

The animal was provided with the rubber duct described and illustrated in a previous publication,^a for the collection of the feces, and with the ordinary urine funnel. During the experiment proper these were worn constantly, both during the preliminary days and the digestion period proper. The apparatus served its purpose excellently, loss of excreta occurring in very few instances.

During the digestion period the excreta were weighed promptly at the end of each twenty-four hours, a sample drawn, after thorough mixing, and taken at once to the laboratory for treatment. There one one-hundredth of the total excretion was weighed out and set aside

^a Penn. Experiment Station, Bulletin No. 42, p. 74.

for a composite sample, formaldehyde being employed as a preservative. At the close of the period these composite samples were thoroughly mixed. In the feces the total nitrogen in the fresh substance was determined by the König method and pepsin-insoluble nitrogen by Kühn's method, while a portion of the composite sample was also air dried at about 60° C. and the air-dry sample subjected to the usual methods of analysis, including the determination of its heat of combustion and of carbon and hydrogen. In the mixed sample of urine the total nitrogen, total carbon, carbon dioxide, hydrogen in organic combination, and heat of combustion were determined.

DIGESTIBILITY OF THE HAY.

As already stated, a preliminary determination of the digestibility of the hay employed was made during November and December. In this trial steer No. 1 received daily 6.804 kilograms (15 pounds) and steer No. 2, 5.443 kilograms (12 pounds) of hay. The live weights, water consumed, and weights of excreta during the digestion trial proper are as shown in Table I of the Appendix.

The percentages of dry matter found in hay and feces were as follows:

Hay:	Per cent.
Preliminary period.....	87.93
Digestion period.....	88.03
Feces:	
Steer No. 1.....	18.77
Steer No. 2.....	19.95

The dry matter of the hay contained, in the preliminary period, 0.853 per cent and in the digestion period 0.775 per cent of total nitrogen, equivalent to 5.33 and 4.84 per cent, respectively, of protein. For the other ingredients the average results upon samples A and B were assumed. The dry matter of the feces had the composition shown in Table II of the Appendix.

Using the averages of the analyses for the preliminary and the digestion periods to represent the composition of the hay consumed, the results upon digestibility were as follows, the details of the computation being shown in Table III of the Appendix:

Percentage digestibility of hay.

Constituents and energy.	Steer No. 1.	Steer No. 2.
	<i>Per cent.</i>	<i>Per cent.</i>
Dry matter	56.92	56.60
Ash.....	44.56	44.15
Organic matter.....	57.52	57.20
Crude protein	38.56	39.62
Crude fiber	59.35	59.07
Nitrogen-free extract.....	58.95	58.46
Ether extract.....	35.58	35.04
Energy	52.78	53.09

The results upon the urine and the nitrogen balance were as follows:

Average weight of urine and percentage of nitrogen.

Animals.	Average weight of urine per day.	Nitrogen in urine.
	Grams.	Per cent.
Steer No. 1	3,677	0.70
Steer No. 2	3,769	.65

Daily nitrogen balance.

Steer No. 1:	Grams.
In food	48.73
In feces	29.94
In urine	25.74
In total excreta	55.68
Loss	6.95
Steer No. 2:	
In food	38.98
In feces	23.55
In urine	24.50
In total excreta	48.05
Loss	9.07

DIGESTIBILITY OF THE MIXED RATIONS.

The same general methods that have been described above were used in the several periods to determine the digestibility of the total rations. As already noted, steer No. 1 only was used for these trials, and the periods, with the exception of the first (Period B), were but two weeks long, the first week being regarded as preliminary. The results for the several periods were as shown below:

Period A (March 26 to April 8, 1902).

This was the third of the four periods, but being the one with the smallest ration it is considered first. The live weights and the weights of the excreta were as shown in Table I of the Appendix. The weight of urine includes 10 c. c. of formalin added as a preservative and, on April 5, 6, 7, and 8, 50 c. c. of distilled water employed to rinse out the tube. The animal entered the calorimeter April 1 and therefore no weight was taken on the 2d, while upon the 3d the weight was taken at 6 p. m. instead of at the regular time. On April 2 a small amount of urine was spilled in the calorimeter. After the animal left the apparatus, this was taken up as completely as possible with distilled water and the weight and nitrogen content of the whole determined. On two days small amounts of feces were also spilled, but were carefully collected and the weight and content of dry matter determined. A residue of 14.9 grams of uneaten hay was left during the two days in the calorimeter.

The following percentages of dry matter were contained in the several samples:

	Per cent.
Hay.....	88.66
Linseed meal	89.46
Feces.....	20.66
Feces spilled:	
April 2	57.58
April 5	31.29

The total amounts of dry matter consumed and excreted in the seven days of the digestion period, together with the averages per day, were, accordingly, as follows:

Feed and excreta.

Feed and excreta.	Fresh weight.	Dry matter.
	<i>Grams.</i>	<i>Grams.</i>
Hay:		
Total in 7 days	22,750.0	20,170.2
Uneaten	14.9	13.7
Eaten	22,735.1	20,156.5
Eaten per day	3,247.9	2,879.5
Linseed meal eaten per day.....	400.0	357.8
Feces:		
Collected in 7 days	45,112.0	9,320.1
Spilled in calorimeter April 2	64.1	37.0
Spilled in stall April 5.....	14.3	4.5
Total excretion.....	45,190.4	9,361.6
Daily excretion	6,455.8	1,337.4

The composition of the dry matter of the feeding stuffs has already been stated on page 11, and that of the dry matter of the feces is shown in Table II of the Appendix.

Basing the computation upon the above daily averages, the digestibility of the total ration, as shown in detail in Table III of the Appendix, was as follows:

Digestibility of the total ration.

Constituents and energy.	Total digested.	Percent-age digesti-bility.
	<i>Grams.</i>	
Dry matter	1,899.9	58.69
Ash.....	68.8	45.14
Organic matter.....	1,831.1	59.36
Proteids	146.8	59.19
Nonproteids ^a	16.3	(100.00)
Crude fiber	642.6	56.17
Nitrogen-free extract	959.2	60.80
Ether extract	66.2	66.80
	<i>Calories.</i>	
Energy	8,427	56.71

^a Assumed to be wholly digestible.

If we assume that the pepsin-insoluble nitrogen of the feces represents the actual undigested proteids of the food, and that the nitrogen soluble in pepsin represents metabolic products, we have the following figures for the real digestibility of the proteids:

Proteids in ration	grams..	248.0
Indigestible proteids in feces	do....	82.4
Digestible	do....	165.6
Percentage digestibility	per cent..	66.77
Metabolic products	grams..	18.8

It will be noted that in this period and one other the proteid nitrogen of the feces as ordinarily determined is less than the pepsin-insoluble nitrogen. It is assumed that this is due to an error in the determination of the former, although there is no direct evidence that such is the fact.

Period B (February 23 to March 11, 1902).

This was the first of the four periods in order of time. The preliminary feeding covered the ten days from February 23 to March 4, inclusive, and the digestion period proper the seven days from March 5 to March 11, inclusive. The animal entered the calorimeter March 4, consequently no live weight was taken on the 5th, and on the 6th was taken at 6 p. m., immediately after leaving the calorimeter. A small amount of feces was spilled in the calorimeter. This was collected at the completion of the test and its weight and content of dry matter determined. Four grams of hay, air-dry weight, were left uneaten in the calorimeter. In reporting weights of urine for March 7 and 9 an error of +1 kilogram was made and the aliquot taken for the composite sample was based on these erroneous weights. Accordingly these two days are given undue weight in the composite sample. The weights given in Table I of the Appendix, however, are the actual weights.

The following are the results of the determinations of dry matter in the several samples of this period:

Hay:	Per cent.
Preliminary period	88.75
Digestion period	88.63
Linseed meal	88.67
Feces	20.15
Feces spilled	25.29

Using the average percentage of dry matter in the hay for the preliminary and the digestion periods as the basis of computation, the amounts of dry matter eaten and excreted were as follows:

Feed and excreta.

Feed and excreta.	Fresh weight.	Dry matter.
	<i>Grams.</i>	<i>Grams.</i>
Hay:		
Total in 7 days	31,717.0	28,129.8
Uneaten	4.0	3.8
Eaten	31,713.0	28,126.0
Eaten per day	4,530.4	4,018.0
Linseed meal eaten per day	400.0	354.7
Feces:		
Collected	59,705.0	12,030.5
Spilled in calorimeter	565.0	142.9
Total excretion	60,267.0	12,173.4
Daily excretion	8,609.6	1,739.1

^a Air-dry weight. Assumed to have had same moisture content as air-dry hay, namely, 4.80 per cent.

Computed as in Period A, the results upon digestibility, as shown in Table III of the Appendix, were as follows:

Digestibility of the total ration.

Constituents and energy.	Total digested.	Percentage digestibility.
	<i>Grams.</i>	
Dry matter	2,633.6	60.23
Ash	93.9	46.60
Organic matter	2,539.7	60.89
Proteids	173.2	57.15
Nonproteids ^a	17.2	(100.00)
Crude fiber	961.5	60.94
Nitrogen-free extract	1,309.3	61.04
Ether extract	78.5	61.28
	<i>Calories.</i>	
Energy	11,700	57.76

^a Assumed to be wholly digestible.

Proteids in ration	grams..	303.1
Indigestible proteids in feces	do....	105.7
Digestible	do....	197.4
Percentage digestibility	per cent..	65.13
Metabolic products	grams..	24.2

Period C (March 12 to March 25, 1902).

This was the second of the four periods, immediately following Period B. The preliminary feeding extended from March 12 to 18,

inclusive, and the digestion period proper from March 19 to 25, inclusive. The animal entered the calorimeter on the 18th, so that no weight was taken on the 19th, and that on the 20th was taken at 6 p. m. There were small mechanical losses of excreta, as shown in Table I of the Appendix. In particular, there was a loss of urine during the calorimeter experiment which was not discovered until several days afterwards. The partially dried residue was then taken up with distilled water, the weight of the solution and its nitrogen content determined, and the content of carbon and of energy assumed to be proportional to the nitrogen. By a misunderstanding two aliquot samples of urine were based upon the net weight, not including the preservative and wash water, so that there is a slight error in sampling in this period.

The percentages of dry matter in the several samples of this period were:

	Per cent.
Hay.....	89.22
Linseed meal.....	89.02
Uneaten hay:	
In calorimeter.....	92.14
In stall.....	79.65
Feces.....	18.32
Feces spilled:	
In calorimeter.....	28.04
In stall.....	36.45

The average amounts of dry matter eaten and excreted daily were, accordingly, as follows:

Feed and excreta.

Feed and excreta.	Fresh weight.	Dry matter.
	<i>Grams.</i>	<i>Grams.</i>
Hay:		
Total in 7 days.....	40,250.0	35,911.1
Uneaten—		
In calorimeter.....	27.1	25.0
In stall.....	20.5	16.3
Total uneaten.....	47.6	41.3
Eaten.....	40,202.4	35,869.8
Eaten per day.....	5,743.2	5,124.3
Linseed meal eaten per day.....	400.0	356.1
Feces:		
Collected.....	89,496.0	16,395.7
Spilled—		
In calorimeter.....	149.0	41.8
In stall.....	117.6	42.9
Total excretion.....	89,762.6	16,480.4
Daily excretion.....	12,823.2	2,354.3

Summarizing the detailed computations of the Appendix, we have the following figures for the digestibility of the ration:

Digestibility of the total ration.

Constituents and energy.	Total digested.	Percentage digestibility.
	<i>Grams.</i>	
Dry matter.....	3,126.1	57.05
Ash.....	112.1	43.96
Organic matter.....	3,014.0	57.68
Proteids.....	179.8	51.27
Nonproteids ^a	17.9	(100.00)
Crude fiber.....	1,121.0	55.89
Nitrogen-free extract.....	1,609.7	59.53
Ether extract.....	85.6	58.19
	<i>Calories.</i>	
Energy.....	13,679	54.42

^a Assumed to be wholly digestible.

Proteids in ration.....	grams..	350.7
Indigestible proteids in feces.....	do...	143.2
Digestible.....	do...	207.5
Percentage digestibility.....	per cent..	59.16
Metabolic products.....	grams..	27.7

Period D (April 9 to 22, 1902).

This was the last period of the series. The preliminary feeding extended from April 9 to 15 and the digestion period proper from the 16th to the 22d, inclusive. The animal entered the calorimeter on the 15th. On the 19th there was a small loss of feces in the stall. This was collected as completely as possible by mechanical means and an aliquot portion of it added to the sample of the main portion.

The several samples of this period contained the following percentages of dry matter:

	Per cent.
Hay.....	87.07
Linseed meal.....	88.6
Hay uneaten:	
April 18.....	92.02
April 22.....	43.73
Feces.....	17.72
Feces spilled.....	74.28

The following tables show the average amounts of dry matter eaten and excreted daily in this period and the final results of the computations of digestibility contained in the Appendix:

Feed and excreta.

Feed and excreta.	Fresh weight.	Dry matter.
	<i>Grams.</i>	<i>Grams.</i>
Hay:		
Total in 7 days	49,000.0	42,664.3
Uneaten April 18	54.0	49.7
Uneaten April 22	31.7	13.9
Total uneaten	85.7	63.6
Total eaten	48,914.3	42,600.7
Eaten per day	6,987.8	6,085.8
Linseed meal eaten per day	400.0	354.4
Feces:		
Collected	116,292.0	20,606.9
Spilled in calorimeter	42.1	31.3
Total excretion	116,334.1	20,638.2
Daily excretion	16,619.2	2,948.3

Digestibility of the total ration.

Constituents and energy.	Total digested.	Percent-age digestibility.
	<i>Grams.</i>	
Dry matter	3,491.9	54.22
Ash	121.9	40.22
Organic matter	3,370.0	54.92
Proteids	224.8	51.75
Nonproteids ^a	30.6	(100)
Crude fiber	1,238.8	51.74
Nitrogen-free extract	1,760.2	57.06
Ether extract	115.6	59.93
	<i>Calories.</i>	
Energy	15,295.0	51.78

^a Assumed to be wholly digestible.

Total proteids of food	grams..	434.4
Indigestible proteids of feces	do....	166.4
Digestible	do....	268.0
Per cent digested	per cent..	61.7
Metabolic products	grams..	43.2

THE URINARY EXCRETION.

Table IV of the Appendix, based upon the weights recorded in Table I, shows the total excretion of nitrogen, carbon, and potential energy in the urine. In those cases in which some was spilled, the

nitrogen content was determined directly, as already noted, and it has been assumed that the content of carbon and of energy was proportional to the nitrogen. The following table gives a summary of the average daily excretion:

Average daily excretion in urine.

Period.	Nitrogen.	Carbon.	Energy.	Energy per gram of carbon.
	<i>Grams.</i>	<i>Grams.</i>	<i>Calories.</i>	<i>Calories.</i>
A.....	36.32	88.1	853	9.68
B.....	33.69	101.3	965	9.53
C.....	34.11	117.6	1,110	9.44
D.....	32.41	124.2	1,210	9.74

It will be noted that the average energy per gram of carbon in these experiments is somewhat less than that found by Kellner,^a the average being 9.6 Calories instead of 10.03 Calories. It, however, corresponds almost exactly with Kellner's results for lean animals on a maintenance ration.

GROWTH OF EPIDERMAL TISSUE.

Except in Period B, the steer was thoroughly brushed immediately before entering the calorimeter and after leaving it, and the hair, dandruff, etc., in the latter case collected. To this was added the small amount brushed up from the floor of the calorimeter. In these samples determinations of nitrogen, carbon, and energy were made with the following results:

Composition of hair, dandruff, etc.

Constituents and energy.	Period A.	Period C.	Period D.
Weight.....grams..	35.8	42.1	32.9
Dry matter.....per cent..	94.22	^b 94.78	94.57
Weight of dry matter.....grams..	33.7	39.9	31.1
In dry matter:			
Nitrogen—			
Percentage.....	7.571	^b 6.49	7.014
Weight.....grams..	2.71	2.73	2.18
Carbon—			
Percentage.....	45.87	^b 41.68	45.23
Weight.....grams..	16.42	17.55	14.07
Energy—			
Per gram.....Calories..	5.020	^b 4.568	5.025
Total.....do.....	179.7	192.3	156.3

^a Landw. Vers. Stat., v. 53, p. 439.

^b Air-dry matter.

Average composition of hair, dandruff, etc.

On the average of the three periods, the amounts of nitrogen, carbon, and energy contained in the brushings were as follows:

Constituents and energy.	Total.	Per day.
Nitrogen .....grams..	2.54	1.3
Carbon.....do....	16.01	8.0
Energy .....Calories..	176.1	88.0

In the computations on the following pages it has been assumed that these figures represent the normal rate of production of hair, epidermis, etc., by the animal during the experiment. They do not, of course, include the matter and energy contained in the growth of hoofs and horns.

THE RESPIRATION CALORIMETER.

The apparatus employed for the determination of the respiratory products and heat is a modification of the respiration calorimeter devised by Atwater and Rosa, and described in Bulletin No. 63 of the Office of Experiment Stations of the United States Department of Agriculture. Our apparatus is essentially the same as theirs, with such increase in size and modifications in details as were necessary to fit it for experiments on domestic animals. It is the intention to publish later a more detailed description of it, but the following outline, together with reference to the bulletin above named, will give a sufficient idea of its general nature.

THE RESPIRATION APPARATUS.

The respiratory part of the apparatus is, in principle, a Pettenkofer apparatus. The ventilation is maintained by means of a large mercurial pump, known as a meter pump, having a capacity, as used, of 50 liters per stroke and running at the rate of about fourteen strokes per minute, the total ventilation being, therefore, about 700 liters per minute. Before entering the apparatus, the external air is passed over ammonia expansion coils connected with an ice machine and thus deprived of the larger part of its moisture. After leaving the apparatus, the air passes through a series of four copper cans immersed in a brine bath cooled by the same machine. Most of the water contained in the outgoing air is deposited in the cans and weighed at the close of a period or subperiod.

A sample of the ingoing air is taken by an aspirator at the rate of about 200 liters in twelve hours. The outgoing air is automatically sampled by the meter pump, which delivers one two-hundredth of the total volume of air into each of two duplicate receivers, from which

it is drawn through a series of absorption tubes by means of an auxiliary air pump.

The samples of both ingoing and outcoming air pass through six U tubes, the first two of which are filled with pumice stone saturated with sulphuric acid, the second two with soda lime, and the last two again with pumice stone and sulphuric acid. The increase in weight of the first pair of tubes is reckoned as water and that of the remaining four tubes as carbon dioxide. The second sulphuric acid tube in every case is used as a check and shows no material gain in weight.

One of the two samples of outcoming air, after passing through the absorption tubes as just noted, is conducted through a copper tube 2.5 cm. in diameter and 154 cm. long, filled with platinized kaolin maintained at a red heat, and then through a second set of absorption tubes. The increases in weight in the latter set represent, of course, the carbon and hydrogen of any combustible gases excreted by the animal. Preliminary tests showed that the apparatus as described is fully sufficient to oxidize the amounts of methane, etc., given off by the animal under the conditions of the experiment. As appears from the above statements, the determination of combustible gases was not duplicated, nor were any simultaneous determinations made upon the ingoing air. Numerous check tests upon the latter, however, were made, as noted below.

The apparatus as described is intended to determine both the carbon dioxide and water excreted by the animal. The results for the latter in the check tests, however, were not satisfactory, apparently on account of evaporation of water from the wooden platform in the apparatus, and the figures for water are not included in the following pages.

THE CALORIMETER.

The respiration apparatus, as above described, is also fitted up as an animal calorimeter. Through a series of copper pipes at the top of the respiration chamber a uniform current of cold water is constantly circulated. The temperature of this water on entering and leaving is read every four minutes by calibrated mercurial thermometers reading to 0.01° C., and the volume of water passing through is measured by means of copper meters holding 100 liters each. From these data the amount of heat brought out by the water current is readily computed.

The walls of the respiration chamber are double, the inner one being of sheet copper and the outer of sheet zinc, with a 7.5 cm. dead-air space between. This inner chamber is surrounded by two double wooden walls inclosing spaces of about 10 cm. between the outer zinc surface of the respiration chamber proper and the first wooden wall and between the latter and the second wooden wall, respectively.

The walls of the respiration chamber proper contain 1,008 iron Ger-

man silver couples, arranged in two hundred and fifty-two groups of four each, distributed as uniformly as possible over top, bottom, and sides of the chamber. The junctions of the couples lie, respectively, in the plane of the copper and of the zinc, and the couples are connected in series to a reflecting galvanometer. Any difference in temperature between the inner copper wall and outer zinc wall is, of course, indicated by a corresponding deflection of the galvanometer. If the zinc wall is shown to be warmer than the copper wall, cold water is circulated through a series of brass pipes in the adjoining air space until equilibrium is restored. If the zinc wall is found to be cooler than the copper wall, the adjoining air space is heated by means of an electric current through German silver heating wires until the galvanometer stands at zero. This regulation is so delicate that with a little practice the copper-zinc wall of the respiration chamber may be maintained practically adiabatic with only minimal fluctuations, which are made to balance each other in the course of an experiment.

By means of a less delicate arrangement on the same plan, the air space between the two wooden walls is maintained at approximately the same temperature as the air space next the zinc wall, thus protecting the latter from fluctuations of room temperature. Frequent measurements of the temperature in the interior of the respiration chamber, both by mercurial thermometers and by means of delicate copper resistance thermometers, enable the withdrawal of heat by the water current to be so regulated as to maintain very nearly a constant temperature in the chamber.

A similar arrangement of thermo-electric couples, water jackets, and electric heating coils permits the temperature of the ingoing air to be kept the same as that of the outcoming air.

By these devices all loss of heat by radiation through the walls of the apparatus or in the air current is avoided and the total amount of heat evolved by the animal under experiment is represented by the heat carried off in the water current plus the latent heat of vaporization of the water removed in the air current. The latter quantity is computed from the weight of the water excreted. As noted on page 24, this determination was not satisfactory, but the error introduced into the heat computation is believed to be small, since any water evaporated from the platform in the calorimeter would reduce the amount of heat measured in the water current by the same amount that it increased that measured as latent heat of water vapor, provided there was no permanent cooling of the platform, which can hardly have occurred to any large extent.

CHECK TESTS.

External air.—As noted, a number of determinations of the combustible gases of the external air were made at different dates, the

results of which have been discussed elsewhere^a and a summary of which is contained in the following table:

Combustible gases in air.

Date.	Volume of air.	Water weighed.	Carbon dioxide weighed.	Per 100 liters air, at 0° C. and 760 mm.	
				Hydrogen.	Carbon.
	Liters.	Gram.	Gram.	Milligram.	Milligram.
October 18, 1901.....	850	0.0150	0.0030	0.22	0.11
November 4, 1901.....	1,250	.0320	.0115	.31	.28
February 3, 1902.....	2,450	.0025	.0040	.01	.05
April 24, 1902.....	2,400	.0530	.0265	.27	.33
May 6, 1902.....	1,200	.0300	.0105	.30	.26

As will be seen, the results are somewhat variable, but at the same time the absolute amounts found are so small as to make the error involved in using these corrections relatively insignificant as compared with the total amounts determined in the experiments on the animal. There appears to be some connection between the meteorological conditions and the amounts of carbon and hydrogen found. Accordingly, the correction derived from the test of February 3 has been applied in computing Periods A, B, and C, and the average of the results of April 24 and May 6 has been used in computing Period D, the meteorological conditions having been similar in the respective cases.

Alcohol check tests.—Several tests of the accuracy of the apparatus were made by burning known amounts of ethyl alcohol and determining the amounts of carbon dioxide, water, and heat evolved, exactly as in experiments with an animal. The alcohol was burned from a large Argand burner to which it was supplied from outside the calorimeter by means of a constant level apparatus. The flame appeared entirely colorless, but very small amounts of combustible gases, apparently consisting of carbon monoxide, were detected by passage over the platinized kaolin. After the lamp had been burning for some time and the apparatus had fully come into equilibrium the air current was shifted to fresh absorption apparatus and the experiment continued for the desired number of hours. The methods were in all respects similar to those of the experiments with the animal, and it seems unnecessary to consume space with a full description or tabulation of them. The theoretical amounts of carbon dioxide and water produced are computed on the assumption that the alcohol was pure ethyl alcohol. For the heat, on the contrary, the results of direct determinations of the heats of combustion of the samples of alcohol used are made the basis of the calculation. These results were:

	Calories per gram.
Sample of January 16 and 29.....	7.1773
Sample of April 29.....	7.2220

^a Fries: Soc. Prom. Agrl. Science, Proceedings, 1902, p. 110.

These figures are somewhat higher than the accepted value for ethyl alcohol and may indicate a slight admixture of higher alcohols.

The final results of the tests were as follows:

Results of alcohol check tests.

Date.	Number of hours.	Weight of alcohol.		Carbon dioxide.			Heat.		
		Hydrated.	Anhydrous.	Computed.	Observed.	Percentage observed.	Computed.	Observed.	Percentage observed.
		<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>		<i>Calories.</i>	<i>Calories.</i>	
January 16, 1902	6	564.85	511.41	977.30	963.15	98.5	3,670.54	3,752.64	102.2
January 29, 1902	6	592.86	536.77	1,025.77	1,017.86	99.2	3,852.66	3,876.76	100.6
April 29, 1902	11	975.34	879.14	1,680.04	1,665.14	99.1	6,347.39	6,395.38	100.8

Apparently there is a slight tendency to a minus error in the determination of carbon dioxide and to a plus error in that of heat.

DETERMINATIONS OF RESPIRATORY PRODUCTS.

As indicated on pages 15-20, a respiration trial was made during each of the four periods. Each respiration trial extended over forty-eight hours continuously, being divided into four subperiods of twelve hours each. The respiration trial began in each case at 6 p. m., but the animal was placed in the apparatus about five hours before this time, so that at the time of beginning the actual trial everything was in equilibrium.

It seems neither practicable nor necessary to reproduce in full the records of these trials, but the essential portions of them are tabulated in the Appendix. The general methods employed may be conveniently illustrated here by the records of the first subperiod of Period C.

RESIDUAL AIR.

Owing to variations in the rate of excretion of the respiratory products, the amounts of the latter contained in the air of the respiration chamber vary more or less at different times. In order to obtain a correction for this source of error, a sample of 25 liters of the air of the chamber was taken by means of an aspirator at the beginning of each subperiod and at the close of the last one, and in this sample water and carbon dioxide were determined by absorption by means of sulphuric acid and soda lime. The total volume of the chamber, up to the cans in which the outgoing water is condensed, is 12,678 liters. The average weight of the animal was 415 kilograms. Assuming a specific gravity of 1, this is equivalent to 415 liters, leaving the net capacity of the apparatus 12,263 liters. The slight errors arising from variations in the weight of the animal and the error in the assumed specific gravity are entirely insignificant. The table below gives the detailed

results for the sample of residual air taken at the end of subperiod 1 of Period C. In computing these results it is assumed that the air in the aspirator was saturated with water vapor at the observed temperature:

Carbon and hydrogen in residual air.

Aspirator reading.....	liters..	25	
Temperature.....	degrees C..	16.4	
Barometer.....	millimeters..	733.86	
Tension of water vapor.....	do....	13.89	
Pressure of air.....	do....	719.97	
25 liters $\times \frac{720}{760} \times \frac{273}{289.4}$	liters, corrected..	22.35	
CO ₂ weighed 0.1050 gram $\times$ 0.50086.....	do....	0.05	
Total volume of sample, dry.....	do....	22.40	
H ₂ O weighed 0.1349 gram $\times$ 1.2434.....	do....	0.16	
Total volume of sample, moist.....	do....	22.56	
Temperature of chamber.....	degrees C..	18.2	
Total volume of air in chamber and connections to cans, 12263 $\times$ $\frac{733.86}{760} \times \frac{273}{291.2}$	liters, corrected..	11,101	
Factor.....		492.06	
In chamber.....	grams..	H ₂ O. 66.34	CO ₂ . 51.67
At end of previous subperiod.....	do....	55.83	62.29
Correction.....	do....	+10.51	-10.62

According to the above figures there was contained in the respiration chamber at the end of the subperiod 66.34 grams of water and 51.67 grams of carbon dioxide, while a similar determination at the beginning of the subperiod showed the presence of 55.83 grams of water and 62.29 grams of carbon dioxide. In other words, 10.51 grams of water had accumulated in the chamber during the subperiod and should be added to that actually weighed, while on the contrary the carbon dioxide of the chamber had diminished during the period by 10.62 grams, and this amount should accordingly be subtracted from that actually observed.

The data for all the samples of residual air, somewhat condensed, will be found in Table V of the Appendix.

TOTAL VENTILATION.

The total volume of air passing through the apparatus is measured by the meter pump. As adjusted for this experiment, one stroke is equivalent to 50 liters. The number of strokes during the subperiod is recorded by a revolution counter. The barometric pressure and the temperature of the air as it enters and leaves the pump are recorded every thirty minutes, the average of these readings being taken to

represent the average temperature and pressure of the air in the pump. The tension of water vapor in this air is computed from the determination of water in the sample taken.

The following are the results observed during Period C, subperiod 1. In this case the whole of the initial sample of residual air and half of that between the first and second subperiods were taken during the first subperiod, and this volume has to be added, of course, to that measured by the meter pump. On the other hand, the volume of methane generated has to be subtracted from the volume as measured by the pump in order to obtain the actual volume of ingoing air.

Total ventilation.

Meter pump, 9,672 strokes at 50 liters	liters..	483,600
Average temperature	degrees C..	13.58
Average barometer	millimeters..	733.96
Tension of water vapor	do....	1.31
Pressure of air	do....	732.65
483,600 liters $\times \frac{732.65}{760} \times \frac{273}{286.58}$	liters, corrected..	444,105.36
Sample of residual air, dry	do....	33.55
Total	do....	444,138.91
Methane generated	do....	66.07
Total ingoing air, dry	do....	444,072.84

The results for the various periods are contained in Table VI of the Appendix.

INGOING AIR.

As already noted, a continuous sample of the ingoing air was taken by means of an aspirator just at the point of entrance to the chamber. The total volume taken was equal to 200 liters in twelve hours, and the water and carbon dioxide in this sample were absorbed in U tubes containing sulphuric acid and soda lime in the manner already described. In computing the results the air in the aspirator is assumed to be saturated with water vapor.

From the following record of Period C, subperiod 1, it appears that the corrected volume of the sample was 177.05 liters, while the previous table shows the total volume of ingoing air to have been 444,072.84 liters. The factor, therefore, by which the results for water and carbon dioxide must be multiplied to obtain the total amount in the ingoing air is 2,508.02, as shown in the table.

Carbon and hydrogen in ingoing air.

Aspirator reading.....	liters..	200
Temperature.....	degrees C..	19
Barometer	millimeters..	733.86
Tension of water vapor	do....	14.42
Pressure of air	do....	719.44
200 liters $\times \frac{719.44}{760} \times \frac{273}{292}$	liters, corrected..	177.00
CO ₂ weighed 0.1045 gram $\times 0.50086$	do....	.05
Total volume of sample, dry.....	do....	177.05
Factor		2,508.2
In 177.05 liters sample	gram..	H ₂ O. 0.2320 CO ₂ . 0.1045
In total ventilation	grams..	581.9 262.11

A summary of all the results on this point is contained in Table VII of the Appendix.

OUTCOMING AIR.

The meter pump is so constructed as to deliver one stroke out of each 200 to each of two receptacles. In each of these samples water and carbon dioxide are determined, and in one of them a determination is also made of hydrogen and carbon in the form of combustible gases. The results of actual weighing, however, are subject to a correction for the number of strokes of the pump. Thus in the subperiod under consideration the total number of pump strokes, as appears from the previous table, was 9,672, while the record shows that each sample was made up of 48 strokes from the pump. This amount would be one two-hundredth of 9,600 strokes, while in reality there were 72 more, of which no sample was taken. In computing the results it is assumed that the air of these remaining strokes had the average composition of the 9,600 preceding, and the results actually observed are accordingly multiplied by the fraction $\frac{3}{3000}$. These corrected results are the ones shown in the following table.

To the moisture found in the air coming from the pump must be added the water condensed in the copper cans, and likewise any water condensed upon the cooling pipes carrying the water current, as well as the small amount in the sample of residual air. Finally, the results so obtained have to be corrected for the composition of the residual air in the manner already explained.

The data for Period C, subperiod 1, are contained in the following table, and the corresponding data for the remainder of the experiment are summarized in Tables VIII, IX, and X of the Appendix.

Carbon and hydrogen added in chamber.

	Before ignition.		After ignition.	
	H ₂ O.	CO ₂ .	H ₂ O.	CO ₂ .
	Grams.	Grams.	Grams.	Grams.
Sample I, corrected	3.2376	12.5741	.....	.....
Sample II, corrected	3.2416	12.4834	0.5486	0.6498
Sum of samples $\times 100$	647.92	2,505.75	α 109.72	α 129.96
Water in cans	2,151.00	.....	.....	.....
Drip water	0.00	.....	.....	.....
Water in absorbers	0.00	.....	.....	.....
In residual sample	.18	.18	.....	.....
Total	2,799.10	2,505.93	.....	.....
Correction for residual air	+10.51	-10.62	.....	.....
In outgoing air	2,809.61	2,495.31	109.72	129.96
In ingoing air	581.90	262.11	b .50	b .79
Added in chamber	2,227.71	2,233.20	109.22	129.18
H = H ₂ O $\div 9$	247.52	.....	12.14	.....
C = CO ₂ $\times 0.2727$ .....	.....	608.99	.....	35.23

 α One sample $\times 200$. b From blank tests, p. 26.

SUMMARY.

The following is a summary of the results obtained for water, carbon dioxide, and hydrocarbons in the several periods:

Carbon and hydrogen excretion.

Period.	Carbon in CO ₂ .	Hydrogen in H ₂ O.	Carbon in hydrocarbons.	Hydrogen in hydrocarbons.
	Grams.	Grams.	Grams.	Grams.
Period A:				
Subperiod 1.....	455.0	201.8	.....	.....
Subperiod 2.....	470.3	232.1	28.2	9.6
First day	925.3	433.9	.....	.....
Subperiod 3.....	464.5	226.5	28.2	9.4
Subperiod 4.....	478.3	228.5	27.0	9.3
Second day	942.8	455.0	55.2	18.7
Average	934.1	444.5	55.2	18.7
Period B:				
Subperiod 1.....	545.6	217.0	32.9	11.0
Subperiod 2.....	516.6	228.3	34.6	11.4
First day	1,062.2	445.3	67.5	22.4
Subperiod 3.....	557.4	247.5	39.1	13.0
Subperiod 4.....	531.6	225.3	34.1	11.5
Second day	1,089.0	472.8	73.2	24.5
Average	1,075.6	459.1	70.4	23.5
Period C:				
Subperiod 1.....	609.0	247.5	35.2	12.1
Subperiod 2.....	585.6	241.7	38.9	13.2
First day	1,194.6	489.2	74.1	25.3

Carbon and hydrogen excretion—Continued.

Period.	Carbon in CO ₂ .	Hydrogen in H ₂ O.	Carbon in hydrocar- bons.	Hydrogen in hydro- carbons.
Period C—Continued.	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>
Subperiod 3.....	600.9	251.7	41.9	14.1
Subperiod 4.....	587.1	264.0	38.4	12.8
Second day.....	1,188.0	515.7	80.4	26.9
Average.....	1,191.3	502.5	77.3	26.1
Period D:				
Subperiod 1.....	646.6	255.2	52.9	17.1
Subperiod 2.....	642.4	248.1	51.7	16.5
First day.....	1,289.0	503.3	104.6	33.6
Subperiod 3.....	651.0	275.2	54.6	17.4
Subperiod 4.....	640.4	261.4	54.0	17.2
Second day.....	1,291.4	536.6	108.6	34.6
Average.....	1,290.2	520.0	106.6	34.1

HYDROCARBON GASES.

In computing the balance of energy it is important to know the nature of the combustible gases given off by the animal in order to be able to compute the amount of potential energy which they contain.

The origin of these gases is ascribed to a fermentation of the carbohydrates of the food in the digestive tract, especially in the paunch of ruminants and the cecum of the horse. From the results of laboratory experiments, Tappeiner concluded that the chief products of this fermentation are organic acids, carbon dioxide, methane, and sometimes free hydrogen, and the presence of all these gases, along with more or less nitrogen and oxygen from the air, in the digestive tract has been demonstrated.

In respiration experiments the combustible gases excreted have been commonly assumed to consist of methane, and the amount of the latter has been computed from the amount of oxidizable carbon found by analysis. The writers are not cognizant of any experiments in which the proportions of carbon and hydrogen in the combustible gases normally excreted by herbivora have been determined.

In our experiments, as already noted, both the carbon and hydrogen of the combustible gases were determined. On the extremely probable assumption that they contain no oxygen, a computation of the ratio of hydrogen to carbon furnishes a clue to the nature of the gases. The following table shows this ratio for the several subperiods, as compared with the theoretical ratio for methane:

Ratio of hydrogen to carbon in combustible gases.

Period A:	
Subperiod 2.....	1:2.906
Subperiod 3.....	1:2.949
Subperiod 4.....	1:2.881
	1:2.915

Period B:

Subperiod 1.....	1: 2. 958	
Subperiod 2.....	1: 2. 993	
		1: 2. 976
Subperiod 3.....	1: 2. 986	
Subperiod 4.....	1: 2. 922	
		1: 2. 954

Period C:

Subperiod 1.....	1: 2. 882	
Subperiod 2.....	1: 2. 928	
		1: 2. 905
Subperiod 3.....	1: 2. 948	
Subperiod 4.....	1: 2. 957	
		1: 2. 952

Period D:

Subperiod 1.....	1: 3. 058	
Subperiod 2.....	1: 3. 095	
		1: 3. 076
Subperiod 3.....	1: 3. 098	
Subperiod 4.....	1: 3. 109	
		1: 3. 103

Average 1: 2. 983

Computed for CH₄..... 1: 2. 976

It will be seen that the ratio corresponds so closely to that for methane as to amount very nearly to a demonstration that only this gas was present.

Computed from the amounts of carbon found, the weights of methane excreted in the several subperiods were as follows:

Period A:	Grams.
Subperiod 1.....	-----
Subperiod 2.....	37. 58
Subperiod 3.....	37. 66
Subperiod 4.....	36. 12
Average per day (subperiods 3 and 4)	73. 78
Period B:	
Subperiod 1.....	43. 99
Subperiod 2.....	46. 16
Subperiod 3.....	52. 23
Subperiod 4.....	45. 50
Average per day.....	93. 94
Period C:	
Subperiod 1.....	47. 06
Subperiod 2.....	51. 93
Subperiod 3.....	56. 02
Subperiod 4.....	51. 31
Average per day.....	103. 16
Period D:	
Subperiod 1.....	70. 69
Subperiod 2.....	69. 01
Subperiod 3.....	72. 92
Subperiod 4.....	72. 07
Average per day.....	142. 35

DETERMINATIONS OF HEAT.

It is impracticable to reproduce here the very voluminous records required for the determination of the heat produced, and it must suffice to indicate the general method and to summarize the main results.

As already explained, the heat given off by the animal as sensible heat is removed from the apparatus in the water current, the amount thus removed being measured by the product of the amount of water passing through the absorbers and the rise in temperature during its passage through the apparatus. As noted, the temperature of the water was taken every four minutes, while the efflux of each 100 liters was noted on the records. In any portion of the experiment during which the rate of flow of water is uniform we may, without sensible error, compute the averages of the ingoing and of the outcoming temperatures and multiply the total weight of water by the difference between the two. Certain corrections are necessary, however.

First. The pipe composing our absorber being of small diameter, there is a not inconsiderable pressure upon the bulbs of the thermometers, and this pressure varies with the rate of flow of the water. Since the pressure is greater upon the ingoing than upon the outcoming thermometer, the effect is to render the observed difference in temperature too small. A correction for this effect was worked out experimentally for the range of pressure used and is applied in the table.

Second. The friction of the water in the absorbers is itself the source of a small amount of heat, which has been computed from the difference in pressure at entrance and exit and the weight of the water passing through the absorbers.

Third. As Atwater and Rosa have shown, it is essential to take account of the variation in the specific heat of water at different temperatures. We have followed their practice, and, assuming the specific heat of water at 20° C. as unity, have expressed all our results in Calories at 20°, using for this purpose the table of the specific heat of water given by those observers.^a

Fourth. Corrections have to be made for the heat introduced into the apparatus or withdrawn from it in case the feed, drink, excreta, and vessels containing them were introduced or removed at a temperature different from that of the calorimeter. The net amount of these corrections, as appears from the table, is ordinarily small, but the single factors are sometimes not inconsiderable. This is especially the case with the feces, where considerable difficulty was experienced in determining the true average temperature of the mass.

The results of these several computations are contained in Table XI of the Appendix. To the heat thus measured is to be added the latent

^aUnited States Department of Agriculture, Office of Experiment Stations Bul. No. 63, p. 56.

heat of water vapor produced in and carried out of the chamber. This is computed from the results for water, assuming the latent heat of vaporization to be 0.592 Calorie per gram.

The following table contains a summary of the amounts of heat measured in the calorimeter in the several periods and subperiods:

Heat measured in calorimeter.

Subperiod.	Heat measured.			
	Period A.	Period B.	Period C.	Period D.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>
First day:				
Subperiod 1	4,438.8	5,174.0	5,495.0	5,797.7
Subperiod 2	4,787.1	5,348.8	5,414.4	5,709.9
Total	9,225.9	10,522.8	10,909.4	11,507.6
Second day:				
Subperiod 3	4,649.6	5,416.4	5,410.3	5,830.8
Subperiod 4	4,700.6	4,849.9	5,308.8	5,720.5
Total	9,350.2	10,266.3	10,719.1	11,551.3

RATE OF HEAT EMISSION.

The readings of the thermometers, which were taken every four minutes, furnish an approximation to a continuous measurement of the rate at which heat was given off by the animal by radiation and conduction. The individual readings are probably subject to some accidental fluctuations. To eliminate these, each three successive readings have been averaged and multiplied by the amount of water passing through the absorbers during the same twelve minutes. The results, expressed in Calories per minute, are represented graphically on Diagram II, the possible effects of slight variations in the temperature of the calorimeter itself being disregarded.

Aside from minor fluctuations, the most marked variations are those produced by the consumption of water and by the change from the standing to the lying position.

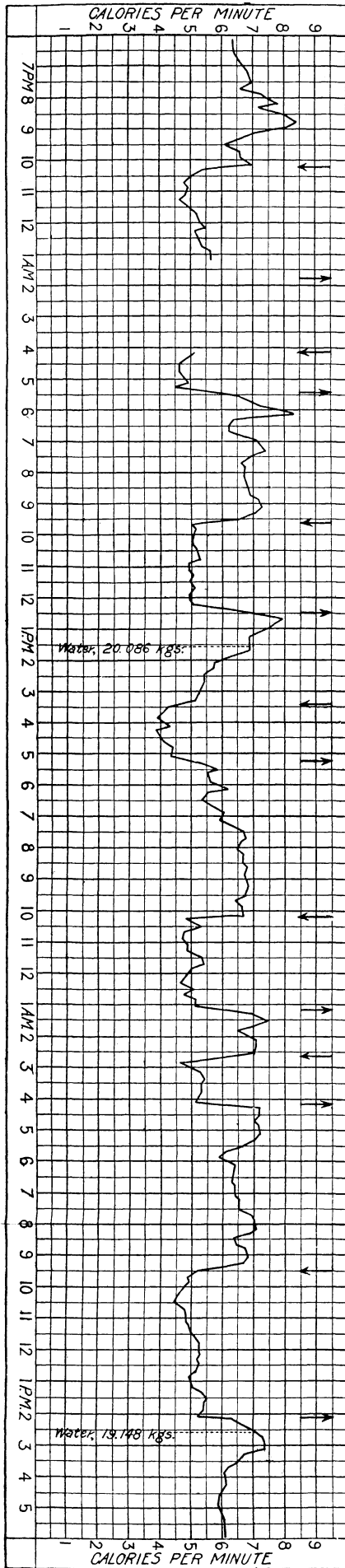
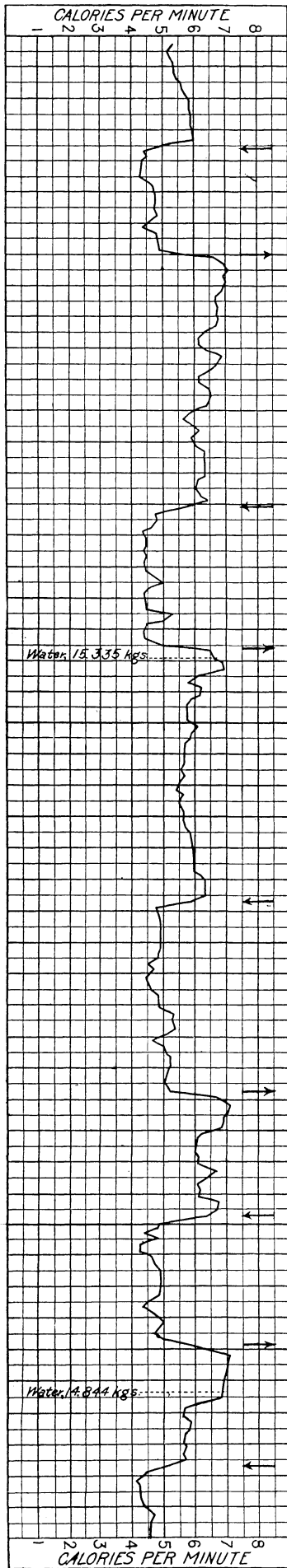
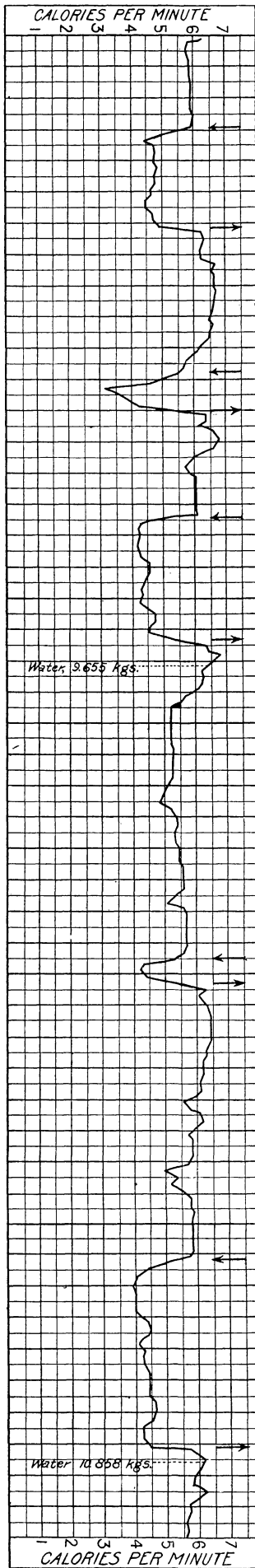
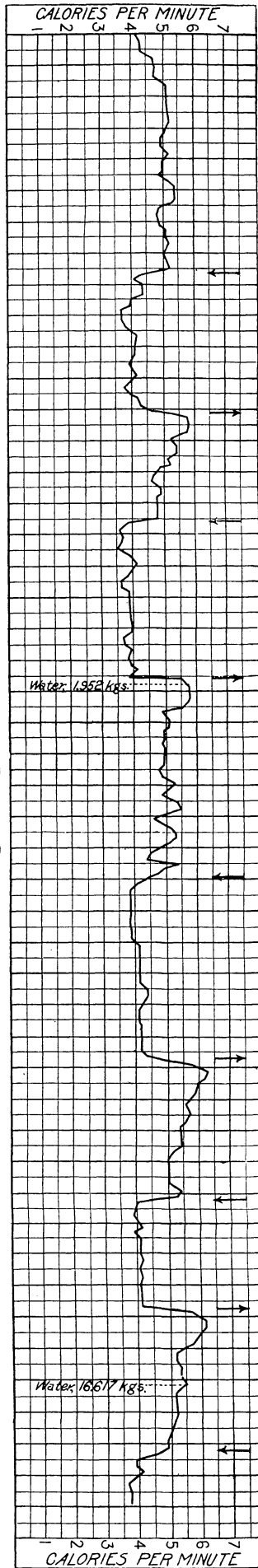
Consumption of water.—It will be noted that in every case the rate at which heat is given off diminishes immediately after the drinking of water and only gradually returns to what may be regarded as its normal rate. Obviously the heat which was produced in the animal was applied in part to raising this water to the temperature of the body, and consequently the rate of emission did not correspond to that of production.

Standing and lying.—The time when the animal stood up or laid down is indicated on the diagram by an arrow. The effect of change of position was very marked and prompt. The heat emission increased rapidly when the animal stood and diminished as promptly when it laid down. This effect has been observed by numerous investigators and naturally ascribed to the increased muscular effort required to maintain the erect posture. In other words, it may be assumed to

indicate a difference in the rate of heat production as well as in that of heat emission. The total amount of this difference was considerable. Computed in the same way as the total heat emission, the results for the several periods of standing and lying were as follows, the table referring only to the amount of heat given off by radiation and conduction and removed from the calorimeter in the water current:

Heat emission.

Period and subperiod.	Time.	Position.	Total heat.	Heat per minute.
Period A:				
Subperiod 1—	<i>Minutes.</i>		<i>Calories.</i>	<i>Calories.</i>
6.00 p. m.—1.38 a. m.	458	Standing	2,311.70	5.0474
1.38 a. m.—6.00 a. m.	262	Lying	1,058.49	4.0406
Subperiod 2—				
6.00 a. m.—6.10 a. m.	10	do	48.87	4.8870
6.10 a. m.—9.34 a. m.	204	Standing	1,109.23	5.437
9.34 a. m.—2.34 p. m.	300	Lying	1,252.79	4.1764
2.34 p. m.—6.00 p. m.	206	Standing	1,118.99	5.4320
Subperiod 3—				
6.00 p. m.—9.00 p. m.	180	do	911.54	5.0597
9.00 p. m.—2.46 a. m.	346	Lying	1,431.09	4.1361
2.46 a. m.—6.00 a. m.	194	Standing	1,107.87	5.7107
Subperiod 4—				
6.00 a. m.—7.10 a. m.	70	do	362.00	5.1714
7.10 a. m.—10.46 a. m.	216	Lying	897.92	4.1570
10.46 a. m.—3.18 p. m.	272	Standing	1,480.58	5.4433
3.18 p. m.—5.02 p. m.	104	Lying	411.03	3.9522
5.02 p. m.—6.00 p. m.	58	Standing	328.85	5.6698
Period B:				
Subperiod 1—				
6.00 p. m.—8.54 p. m.	174	do	1,045.70	6.0098
8.54 p. m.—12.06 a. m.	192	Lying	914.35	4.7622
12.06 a. m.—4.42 a. m.	276	Standing	1,753.10	6.3518
4.42 a. m.—6.00 a. m.	78	Lying	335.04	4.2954
Subperiod 2—				
6.00 a. m.—6.02 a. m.	2	do	8.98	4.4900
6.02 a. m.—9.26 a. m.	204	Standing	1,276.59	6.2578
9.26 a. m.—1.18 p. m.	232	Lying	1,021.10	4.4013
1.18 p. m.—6.00 p. m.	282	Standing	1,768.78	6.2722
Subperiod 3—				
6.00 p. m.—11.28 p. m.	328	do	1,892.71	5.7704
11.28 p. m.—12.16 a. m.	48	Lying	202.22	4.2129
12.16 a. m.—6.00 a. m.	344	Standing	2,002.49	5.8212
Subperiod 4—				
6.00 a. m.—9.08 a. m.	188	do	1,069.89	5.6910
9.08 a. m.—3.14 p. m.	366	Lying	1,587.96	4.3414
3.14 p. m.—6.00 p. m.	166	Standing	977.52	5.8887
Period C:				
Subperiod 1—				
6.15 p. m.—9.26 p. m.	191	do	1,082.21	5.6660
9.26 p. m.—1.00 a. m.	214	Lying	993.79	4.6439
1.00 a. m.—6.15 a. m.	315	Standing	2,095.65	6.6529
Subperiod 2—				
6.15 a. m.—9.06 a. m.	171	do	1,057.30	6.1830
9.06 a. m.—1.32 p. m.	266	Lying	1,244.66	4.6790
1.32 p. m.—6.15 p. m.	283	Standing	1,799.81	6.3598



Heat emission—Continued.

Period and subperiod.	Time.	Position.	Total heat.	Heat per minute.
Period C—Continued.				
Subperiod 3—	<i>Minutes.</i>		<i>Calories.</i>	<i>Calories.</i>
6.15 p. m.—9.42 p. m.	207	Standing	1,237.13	5.9764
9.42 p. m.—3.42 a. m.	360	Lying	1,791.27	4.9755
3.42 a. m.—6.15 a. m.	153	Standing	1,047.10	6.8438
Subperiod 4—				
6.15 a. m.—7.42 a. m.	87	do	571.79	6.5723
7.42 a. m.—11.50 a. m.	248	Lying	1,183.33	4.7715
11.50 a. m.—3.38 p. m.	228	Standing	1,431.22	6.2772
3.38 p. m.—6.15 p. m.	157	Lying	702.80	4.4764
Period D:				
Subperiod 1—				
6.00 p. m.—10.12 p. m.	252	Standing	1,713.90	6.8011
10.12 p. m.—1.44 a. m.	212	Lying	1,110.29	5.2372
1.44 a. m.—4.04 a. m.	140	Standing	806.18	5.7584
4.04 a. m.—5.22 a. m.	82	Lying	519.45	6.3348
5.22 a. m.—6.00 a. m.	34	Standing	294.01	8.6473
Subperiod 2—				
6.00 a. m.—9.36 a. m.	216	do	1,495.85	6.9252
9.36 a. m.—12.30 p. m.	174	Lying	889.19	5.1103
12.30 p. m.—3.22 p. m.	172	Standing	1,109.46	6.4503
3.22 p. m.—5.18 p. m.	116	Lying	487.07	4.1989
5.18 p. m.—6.00 p. m.	42	Standing	260.18	6.1948
Subperiod 3—				
6.00 p. m.—10.10 p. m.	250	do	1,597.64	6.3905
10.10 p. m.—1.10 a. m.	180	Lying	911.21	5.0623
1.10 a. m.—2.36 a. m.	86	Standing	607.46	7.0634
2.36 a. m.—4.10 a. m.	94	Lying	490.35	5.2165
4.10 a. m.—6.00 a. m.	110	Standing	750.03	6.8184
Subperiod 4—				
6.00 a. m.—9.26 a. m.	206	do	1,368.14	6.6413
9.26 a. m.—2.12 p. m.	286	Lying	1,455.33	5.0886
2.12 p. m.—6.00 p. m.	228	Standing	1,449.62	6.3580

The value of results computed from determinations extending over an hour or less may be doubted. If we take for each period the determinations covering three hours or more, disregarding the artificial division into subperiods, we have for the average heat emission per minute for the several periods the figures of the following table:

Average heat emission per minute.

Period.	Lying.	Standing.
Period A:		
Minutes	number..	
Total heat	Calories..	
Heat per minute.....	do....	
Ratio	do....	
Period B:		
Minutes	number..	
Total heat	Calories..	
Heat per minute.....	do....	
Ratio	do....	

Average heat emission per minute—Continued.

Period.	Lying.	Standing.
Period C:		
Minutes.....number..	1,088	1,635
Total heat.....Calories..	5,213.0	10,322.2
Heat per minute.....do....	4.791	6.313
Ratio.....do....	1	1.318
Period D:		
Minutes.....number..	678	1,338
Total heat.....Calories..	3,476.8	8,929.4
Heat per minute.....do....	5.128	6.673
Ratio.....do....	1	1.301

The figures of the above table relate only to the amount of heat brought out by the water current—that is, to the heat given off by radiation and conduction. No similar measurement could be made of the heat removed as latent heat of water vapor, which constituted approximately one-fourth of the total quantity given off, but if we assume that it increased and decreased in proportion to the heat brought out by the water current we can readily compute its amount. This hypothesis may be regarded as one extreme, the other being the hypothesis that the amount of heat carried off as latent heat of water vapor was unaffected by the posture of the animal.

The following table shows the amount of heat measured in the water current and the amount of heat carried out of the calorimeter as latent heat of water vapor in the several subperiods. In this table the corrections for food, excreta, etc., are made in the heat carried off by the water current.

Heat in water current and latent heat of water vapor.

Period and subperiod.	Time passed standing.	Heat measured in water current.	Heat as latent heat of water vapor.	Per cent of total heat removed in water vapor.
Period A:	<i>Per cent.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Per cent.</i>
Subperiod 1.....	63.62	3,363.9	1,074.9	24.21
Subperiod 2.....	56.95	3,550.5	1,236.6	25.83
Subperiod 3.....	51.95	3,443.0	1,206.7	25.95
Subperiod 4.....	55.56	3,483.3	1,217.3	25.90
Average per day.....	57.02	6,920.3	2,367.8	25.49
Period B:				
Subperiod 1.....	62.50	4,017.5	1,156.5	22.35
Subperiod 2.....	67.50	4,132.8	1,216.1	22.73
Subperiod 3.....	93.33	4,097.9	1,318.4	24.34
Subperiod 4.....	49.17	3,649.7	1,200.2	24.75
Average per day.....	68.13	7,949.0	2,445.6	23.53

Heat in water current and latent heat of water vapor—Continued.

Period and subperiod.	Time passed standing.	Heat measured in water current.	Heat as latent heat of water vapor.	Per cent of total heat removed in water vapor.
Period C:	<i>Per cent.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Per cent.</i>
Subperiod 1.....	70.28	4,176.2	1,318.8	24.00
Subperiod 2.....	63.06	4,126.5	1,287.9	23.79
Subperiod 3.....	50.00	4,069.1	1,341.1	24.79
Subperiod 4.....	43.75	3,902.1	1,406.8	26.56
Average per day.....	56.77	8,137.0	2,677.3	24.76
Period D:				
Subperiod 1.....	59.17	4,438.2	1,359.5	23.45
Subperiod 2.....	59.73	4,388.1	1,321.8	23.15
Subperiod 3.....	61.95	4,364.4	1,466.4	25.15
Subperiod 4.....	60.28	4,327.9	1,392.6	24.34
Average per day.....	60.28	8,759.3	2,770.2	24.03

As the foregoing table shows, there were considerable variations in the time spent standing and lying in the several periods—a fact which would necessarily tend to vitiate to some extent a comparison of the results. This we can to a degree eliminate by computing on the above two hypotheses the amount of heat which would have been produced had the animal stood or laid down during the whole experiment. Thus in Period A the average amount of heat brought out in the water current was, while lying, 4.135 Calories per minute; while standing, 5.304 Calories per minute. Multiplying these figures by 1,440 gives the total amount of heat given off by radiation and conduction in twenty-four hours, namely, while lying, 5,955 Calories; while standing, 7,638 Calories. In this period, however, as appears in the last table, the heat given off by radiation and conduction constituted 74.51 per cent of the total heat given off. Dividing by this factor we have, on the first hypothesis, for the total computed heat production, lying, 7,993 Calories; standing, 10,250 Calories.

Upon the second hypothesis we should simply add the amount of heat actually measured as latent heat of water vapor to the amount of heat brought out in the water current as computed above, making the totals, respectively, for lying, 8,323 Calories; for standing, 10,006 Calories. The following table contains the results computed upon both of the above hypotheses, as compared with the results actually observed:

Heat emission.

Period.	Observed.	Computed lying.		Computed standing.	
		First hypothesis.	Second hypothesis.	First hypothesis.	Second hypothesis.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>
A.....	9,288	7,993	8,323	10,251	10,006
B.....	10,395	8,399	8,869	11,334	11,114
C.....	10,814	9,170	9,576	12,083	11,769
D.....	11,529	9,722	10,154	12,650	12,380

HEAT EMISSION AND HEAT PRODUCTION.

The figures of the above tables show the amounts of heat given off by the animal. The heat emitted by the animal, however, is equivalent to the amount of heat actually produced only when the initial and final states of the animal are the same. Consequently there may be, according to circumstances, either a storage of heat in the body or an emission of heat produced in a previous period. In this respect there are two principal sources of error: First, variations in the body temperature of the animal, and, second, a storage or loss of matter in the body. As regards the first of these sources of error, it has been assumed that under normal and uniform conditions the body temperature would be substantially the same at the same hour of the day. We have not been able as yet to make systematic determinations of the body temperature of cattle as a check upon this assumption. That the body temperature may be affected in particular by the consumption of water is rendered probable by the observations upon the rate of heat emission just considered. It is evident that for a time after drinking, the average temperature of the animal plus the water drunk must be somewhat reduced, and our results upon the rate of heat emission strongly suggest that this effect may continue for a considerable time. Our animal was watered less than five hours before leaving the calorimeter and it seems possible that his body temperature was not fully restored to the normal by this time, particularly in Periods C and D.

If the animal stores up matter in its body, there must necessarily be a corresponding storing up of heat, since the matter which is stored was consumed in the food at a temperature considerably below that of the body. On the other hand, if there is a loss of matter from the body in any one of the various excreta, the temperature of this matter is reduced (either actually or by calculation) to that of the surrounding air before it leaves the calorimeter, and this heat which was previously stored up in the body is measured along with that actually produced during the experiment. The above statements are, of course, true, whatever be the kind of matter stored up or given off, but the income and outgo of water is of especial importance in this respect, both because of its large amount and because of the high specific heat of water. Indeed, a very simple calculation serves to show that in these experiments the difference in the income and outgo of dry matter does not materially affect the computation of the balance of energy, and that consequently only the income and outgo of water need be considered.

From the data contained in the various tables of the Appendix is compiled the following table, showing the income and outgo of water by the animal and the consequent gain or loss of heat on each day of the

calorimeter experiments. As regards the urine the figures are approximate only. The dry matter was not determined, but its amount has been computed on the assumption that it is proportional to the specific gravity. The body temperature has been assumed to be 38.5°C ., while that of the calorimeter in every case was 18.2°C . In the case of feces spilled in the calorimeter the water remaining in them when sampled has been divided equally between the two days. The amount of urine spilled has been calculated to the fresh weight upon the basis of its nitrogen content:

Approximate water balance.

Period.	Income.	Outgo.
Period A:		
April 2—	<i>Grams.</i>	<i>Grams.</i>
Hay	371	.....
Linseed meal.....	42	.....
Water	1,952	.....
Feces.....	.....	4,913
Urine.....	.....	3,530
Water vapor.....	.....	3,905
Balance	9,983	.....
	12,348	12,348
April 3—		
Hay	371	.....
Linseed meal.....	42	.....
Water	16,617	.....
Feces.....	.....	5,692
Urine.....	.....	4,563
Water vapor.....	.....	4,094
Balance .....	.....	2,681
	17,030	17,030
Period B:		
March 5—		
Hay	513	.....
Linseed meal.....	45	.....
Water	9,486	.....
Feces.....	.....	8,364
Urine.....	.....	3,073
Water vapor.....	.....	4,008
Balance	5,401	.....
	15,445	15,445
March 6—		
Hay	513	.....
Linseed meal.....	45	.....
Water	10,630	.....
Feces.....	.....	8,712
Urine.....	.....	2,514
Water vapor.....	.....	4,254
Balance	4,292	.....
	15,480	15,480

Approximate water balance—Continued.

Period.	Income.	Outgo.
Period C:		
March 19—	<i>Grams.</i>	<i>Grams.</i>
Hay	626	.....
Linseed meal	44	.....
Water	15,335	.....
Feces		10,774
Urine		3,280
Water vapor		4,403
Balance	2,452	.....
	18,457	18,457
March 20—		
Hay	626	.....
Linseed meal	44	.....
Water	14,844	.....
Feces		11,620
Urine		3,235
Water vapor		4,642
Balance	3,983	.....
	19,497	19,497
Period D:		
April 16—		
Hay	914	.....
Linseed meal	46	.....
Water	20,086	.....
Feces		14,324
Urine		4,499
Water vapor		4,529
Balance	2,306	.....
	23,352	23,352
April 17—		
Hay	914	.....
Linseed meal	46	.....
Water	19,148	.....
Feces		12,466
Urine		4,117
Water vapor		4,829
Balance	1,304	.....
	21,412	21,412

Upon the basis of the above figures the actual heat production has been computed as shown in the following table, the difference between the income and outgo of water, expressed in kilograms, being multiplied by 20.3, the difference in temperature, to obtain the correction:

Heat production.

Period.	Measured in calorim- eter.	Correction for water.	Heat pro- duced.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>
Period A:			
First day	9,225.9	-200.6	9,025.3
Second day	9,350.2	+ 54.4	9,404.6
Average			9,215.0
Period B:			
First day	10,522.8	-109.6	10,413.2
Second day	10,266.3	- 87.1	10,179.2
Average			10,296.2
Period C:			
First day	10,909.4	- 49.8	10,859.6
Second day	10,719.1	- 80.9	10,638.2
Average			10,748.9
Period D:			
First day	11,507.6	- 46.8	11,460.8
Second day	11,551.3	- 26.5	11,524.8
Average			11,492.8

Making the same average corrections in the results as computed on page 39 for the standing and lying positions, we have the following as the final averages for the heat production:

Averages for heat production.

Period.	Observed.	Computed lying.		Computed standing.	
		First hypothesis.	Second hypothesis.	First hypothesis.	Second hypothesis.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>
A	9,215	7,920	8,250	10,178	9,933
B	10,296	8,800	8,770	11,235	11,015
C	10,749	9,105	9,511	12,018	11,704
D	11,493	9,686	10,118	12,614	12,344

THE BALANCE OF MATTER.

Considering the figures for epidermal tissues on page 23 to represent the average rate of growth of hair, etc., we may subdivide the gain or loss as ordinarily computed into the growth of these tissues and the real gain or loss of the proteids and fat in the body, as has been done in the computations which follow:

THE NITROGEN AND CARBON BALANCE.

The income and outgo of nitrogen and carbon are shown in the following table. The figures for hydrogen are omitted for the reason

that, as explained on page 24, the results for water were not found to be satisfactory:

Income and outgo of nitrogen and carbon per day and head.

Period.	Nitrogen.		Carbon.	
	Income.	Outgo.	Income.	Outgo.
Period A:	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>
Hay	23.4	.....	1,337.6	.....
Linseed meal.....	22.2	.....	172.5	.....
Feces .....	.....	16.2	.....	649.8
Urine.....	.....	36.3	.....	88.1
Carbon dioxide.....	.....	.....	.....	934.1
Hydrocarbons .....	.....	.....	.....	55.2
Epidermal tissue .....	.....	1.3	.....	8.0
Balance	8.2	.....	225.1	.....
	53.8	53.8	1,735.2	1,735.2
Period B:				
Hay	32.5	.....	1,876.8	.....
Linseed meal.....	22.1	.....	170.7	.....
Feces .....	.....	20.8	.....	858.0
Urine.....	.....	33.7	.....	101.3
Carbon dioxide.....	.....	.....	.....	1,075.6
Hydrocarbons .....	.....	.....	.....	70.4
Epidermal tissue .....	.....	1.3	.....	8.0
Balance	1.2	.....	65.8	.....
	55.8	55.8	2,113.3	2,113.3
Period C:				
Hay	40.6	.....	2,366.9	.....
Linseed meal.....	21.8	.....	172.5	.....
Feces .....	.....	27.4	.....	1,146.1
Urine.....	.....	34.1	.....	117.6
Carbon dioxide.....	.....	.....	.....	1,191.3
Hydrocarbons .....	.....	.....	.....	77.3
Epidermal tissue .....	.....	1.3	.....	8.0
Balance	.4	.....	.9	.....
	62.8	62.8	2,539.4	2,539.4
Period D:				
Hay	56.4	.....	2,831.7	.....
Linseed meal.....	21.9	.....	172.6	.....
Feces .....	.....	33.5	.....	1,428.7
Urine.....	.....	32.4	.....	124.2
Carbon dioxide.....	.....	.....	.....	1,290.2
Hydrocarbons .....	.....	.....	.....	106.6
Epidermal tissue .....	.....	1.3	.....	8.0
Balance .....	.....	11.1	.....	46.7
	78.3	78.3	3,004.3	3,004.3

GAIN OR LOSS OF PROTEIN AND FAT.

Excluding the amount of epidermal tissue produced, the gain or loss of protein and fat has been computed in the usual manner, using Köhler's^a figures for the composition of the nitrogenous tissue of

^aZeit. physiol. Chem., v. 31, p. 479.

cattle, namely, nitrogen 16.67 per cent and carbon 52.54 per cent. In other words, body protein is equivalent to nitrogen multiplied by 6. In the computation of fat from carbon the usual factor (1.3) has been employed.

Gain or loss of protein and fat per day and per head.

Period.	Gain of nitrogen.	Equivalent protein (N×6).	Gain of carbon.			Equivalent gain of fat.
			Total.	As protein.	As fat.	
	Grams.	Grams.	Grams.	Grams.	Grams.	Grams.
A.....	- 8.2	-49.2	-225.1	-25.9	-199.2	-259.0
B.....	- 1.2	- 7.2	- 65.8	- 3.8	- 62.0	- 80.6
C.....	- .4	- 2.4	- .9	- 1.3	+ .4	+ .5
D.....	+11.1	+66.6	+ 46.7	+35.0	+ 11.7	+ 15.2

THE BALANCE OF ENERGY.

In these experiments we have direct determinations of all the factors of income and outgo of energy, except the potential energy of the methane excreted and that of the tissue gained by the animal. The energy of the methane, however, may be safely computed from its amount, its heat of combustion at constant pressure being 13.344 Calories per gram. The energy of the gain of tissue by the animal may be estimated in the usual way from the computed amounts of protein and fat given above, using the factors 5.7 Calories and 9.5 Calories per gram, respectively. Having done this, we are in position to compare the income with the outgo of energy, and thus to check to a certain extent the accuracy of our experiments. The following table contains such a comparison for each period. The difference between income and outgo, which has been entered in the table under the heading "Error," shows, of course, the extent to which our results appear to deviate from those required by the law of the conservation of energy:

Balance of energy per day and per head.

Period.	Income.	Outgo.
	Calories.	Calories.
Period A:		
Hay	13,085	.....
Linseed meal.....	1,824	.....
Feces		6,432
Urine.....		853
Methane.....		984
Epithelial growth		88
Heat		9,215
Loss by body—		
Protein	280	.....
Fat	2,461	.....
Error		28
	17,600	17,600

Balance of energy per day and per head—Continued.

Period.	Income.	Outgo.
Period B:	<i>Calories.</i>	<i>Calories.</i>
Hay.....	18,463	.....
Linseed meal.....	1,811	.....
Feces.....		8,574
Urine.....		965
Methane.....		1,253
Epithelial growth.....		88
Heat.....		10,296
Loss by body—		
Protein.....	41	.....
Fat.....	766	.....
Error.....	95	.....
	21,176	21,176
Period C:		
Hay.....	23,321	.....
Linseed meal.....	1,814	.....
Feces.....		11,456
Urine.....		1,110
Methane.....		1,374
Epithelial growth.....		88
Heat.....		10,749
Loss by body (protein).....	14	.....
Gain by body (fat).....		5
Error.....		367
	25,149	25,149
Period D:		
Hay.....	27,727	.....
Linseed meal.....	1,811	.....
Feces.....		14,243
Urine.....		1,210
Methane.....		1,896
Epithelial growth.....		88
Heat.....		11,493
Gain by body—		
Protein.....		380
Fat.....		144
Error.....		84
	29,538	29,538

Except in Period C, the discrepancy in the results is relatively small and may very well be ascribed in part to the uncertainties involved in the method of computing the energy of tissue gained or lost.

Comparing the heat production actually observed with that computed in the usual way by subtracting the energy of the excreta plus gain from the energy of the food, we have the following:

Heat production per day.

Period.	Computed.	Observed.	Computed ÷ observed.
	<i>Calories.</i>	<i>Calories.</i>	
A	9,243	9,215	100.3
B	10,201	10,296	99.1
C	11,116	10,749	103.4
D	11,577	11,493	100.7

Only in Period C does the difference reach 1 per cent of the total amount of heat measured.

DISCUSSION OF RESULTS.

THE DIGESTIBILITY OF THE RATIONS.

Bringing together the results tabulated in Table III of the Appendix and summarized also under the several periods, we have the following figures for the percentage digestibility of the total ration for the several periods:

Percentage digestibility.

Constituents and energy.	Period A.	Period B.	Period C.	Period D.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Dry matter	58.69	60.23	57.05	54.22
Ash.	45.14	46.60	43.96	40.22
Organic matter.....	59.36	60.89	57.68	54.92
Proteids	59.19	57.15	51.27	51.75
Nonproteids ^a	[100.00]	[100.00]	[100.00]	[100.00]
Crude fiber	56.17	60.94	55.89	51.74
Nitrogen-free extract.....	60.80	61.04	59.53	57.06
Ether extract.....	66.80	61.28	58.19	59.93
Energy	56.71	57.76	54.42	51.78

^a Assumed.

Periods B, C, and D show a decrease in the percentage digestibility as the amount of the ration and the proportion of hay was increased. Period A, however, on the lightest ration and with the smallest proportion of hay, is an exception to this rule, the digestibility being somewhat lower than in Period B. It will be recalled that this period followed in order of time Period C—that is, a period in which a considerably larger ration was fed. It is not impossible that the apparently lower digestibility in Period A may arise from the fact that the animal had not quite come into equilibrium with the new ration, but

was still excreting too large an amount of feces. This supposition is, to some extent, supported by the figures for the live weight of the animal as represented on Diagram I, from which it seems that the weight of the animal on the first two days of the experiment had not reached its lowest point.

Taking the figures for the organic matter as affording the most satisfactory measure of variations in digestibility, we find that the decrease in digestibility in Periods B, C, and D is very regular. Undoubtedly this is due in part to the larger proportion of hay as compared with linseed meal, but with the comparatively small amount of the latter fed (5.5 to 11.1 per cent of the dry matter of the ration) no great difference could be caused in this way. If we assume for the percentage digestibility of linseed meal the figures reported by Lindsey,^a namely—

	Per cent.
Dry matter	78.7
Organic matter.....	81.2
Protein.....	88.8
Crude fiber.....	57.0
Nitrogen-free extract	77.6
Ether extract.....	88.6

we can compute the probable percentage digestibility of the hay itself in the several periods with the following results:

Computed digestibility of hay.

Constituents.	Period A.	Period B.	Period C.	Period D.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Dry matter	56.20	58.60	55.54	52.80
Organic matter.....	57.02	58.79	56.15	53.39
Proteids	35.02	38.96	34.39	39.54
Nonproteids ^a	[100.00]	[100.00]	[100.00]	[100.00]
Crude fiber.....	56.15	61.02	55.86	51.56
Nitrogen-free extract	59.04	59.79	58.47	56.03
Ether extract.....	54.08	50.55	48.38	53.26

^a Assumed.

After substantially eliminating in this way the effects of the varying proportion of linseed meal, we find that the digestibility of the hay for Periods B, C, and D shows a regular decrease. On the other hand, if we make the calculation in the reverse way, by using the figures obtained in the preliminary period to represent the digestibility of the hay and computing from these the digestibility of linseed meal for the several periods, we get exceedingly divergent and, in one case, impossible results, the computed percentages for organic matter being—

	Per cent.		Per cent.
Period A.....	75.55	Period C.....	62.32
Period B.....	101.10	Period D.....	12.58

^a Massachusetts Experiment Station, Report 1893, pp. 169-173.

It seems clear, then, that in these experiments, contrary to the generally accepted view, the digestibility of the hay decreased sensibly as the amount fed increased.

METABOLIZABLE ENERGY.

A certain proportion of the total or gross energy of the food consumed by an animal escapes from the body as the potential energy of the various excreta, while the remainder is, or is capable of being, converted into the kinetic form in the body. Since this latter portion alone can be considered to be of any direct use to the animal, the term available energy or, more specifically, gross available energy, has been applied to it. As one of us has recently pointed out,^a however, and as will appear in the further discussion of these results, there are not wanting indications that a portion of this so-called available energy may in some instances be of no direct use to the organism; that is, it may neither serve immediately to maintain the vital processes nor add to the store of potential energy in the body, but simply increase the heat production of the animal. We therefore venture to propose the substitution for the term "gross available energy" of the term "metabolizable energy" as equivalent to energy of food minus energy of excreta. Although not particularly euphonious, this term has the advantage of expressing the facts of the case while avoiding any implications regarding the uses to which this energy is put in the body as well as the necessity of using the word "available" in two senses.

The data of the foregoing pages enable us to compute the metabolizable energy of the rations in the several periods. Before doing so, however, a certain correction is necessary in the energy of the urine. For example, in Period A the animal lost 8.2 grams of body nitrogen, corresponding to a loss of 49.2 grams of protein. According to Rubner's results, the potential energy of the urine is increased by 7.45 Calories for each gram of urinary nitrogen coming from the oxidation of body protein. In this case, then, the urine contained $3.2 \times 7.45 = 61$ Calories of energy not derived from the potential energy of the food but from that of body tissue. It is plain, then, that the potential energy of the urine must be diminished by this amount before it is subtracted from the gross energy of the food in order to get the true metabolizable energy of the latter. The corresponding corrections for the several periods, computed in this way, are as follows:

^aArmsby: Principles of Animal Nutrition, Chap. XII.

Corrected energy of urine.

Period.	Gain of nitrogen.	Equivalent energy.	Corrected energy of urine.
	Grams.	Calories.	Calories.
A.....	— 8.2	—61	792
B.....	— 1.2	— 9	956
C.....	— .4	— 3	1,107
D.....	+11.1	+83	1,293

Using these corrected figures, the metabolizable energy of the total ration for the several periods was as follows:

Metabolizable energy of the total ration.

Feed and excreta.	Period A.		Period B.		Period C.		Period D.	
	Feed.	Excreta.	Feed.	Excreta.	Feed.	Excreta.	Feed.	Excreta.
	Calories.	Calories.	Calories.	Calories.	Calories.	Calories.	Calories.	Calories.
Hay.....	13,035	.....	18,463	.....	23,321	.....	27,727	.....
Linseed meal.....	1,824	.....	1,811	.....	1,814	.....	1,811	.....
Feces.....	.....	6,432	.....	8,574	.....	11,456	.....	14,243
Urine (corrected).....	.....	792	.....	956	.....	1,107	.....	1,293
Methane.....	.....	984	.....	1,253	.....	1,374	.....	1,896
Metabolizable.....	.....	6,651	.....	9,491	.....	11,198	.....	12,106
Total.....	14,859	14,859	20,274	20,274	25,135	25,135	29,538	29,538

The relation of metabolizable energy to the amount of matter in the food may be expressed as Calories per gram of the total or of the digested organic matter, with the following results:

Metabolizable energy per gram of organic matter.

Period.	Organic matter of rations.		Metabolizable energy.		
	Total.	Digested.	Total.	Per gram of total organic matter.	Per gram of digested organic matter.
	Grams.	Grams.	Calories.	Calories.	Calories.
A.....	3,085	1,831	6,651	2.156	3.633
B.....	4,171	2,540	9,491	2.275	3.736
C.....	5,225	3,014	11,198	2.143	3.716
D.....	6,137	3,370	12,106	1.972	3.592

It is of interest also to compute the proportion of the potential energy of the food which was metabolizable. This likewise may be computed upon the gross energy of the total ration or upon the energy of the apparently digested matter, with the results shown in the following table. These percentages are, in a sense, comparable with digestion coefficients; that is to say, they show what percentage of the

gross energy of the total or of the digested matter, respectively, was capable of conversion into the kinetic form:

Percentage of total energy metabolized.

Period.	Gross energy.		Metabolizable energy.	Percentage metabolizable.	
	Total.	Of digested matter.		Of total energy.	Of energy of digested matter.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Per cent.</i>	<i>Per cent.</i>
A	14,859	8,427	6,651	44.76	78.93
B	20,274	11,700	9,491	46.81	81.12
C	25,135	13,679	11,198	44.56	81.87
D	29,538	15,295	12,106	40.98	79.14

It appears that the percentage of the total energy of the food which was metabolized diminished as the amount of the ration increased, as was the case with the percentage digestibility. On the other hand, the percentages computed upon the energy of the digested matter are fairly uniform, thus showing that in these experiments the chief factor affecting the percentage of energy metabolizable was the digestibility of the rations—that is, the loss in the feces.

As already noted, the lower figures for digestibility in Period A may perhaps be attributed to excessive excretion, due to the previous heavier ration. If we assume that the true percentage metabolizable for Period A was 47 instead of 44.76, as computed, then the total metabolizable energy for that period would be 6,979 Calories instead of 6,651 Calories. This corrected figure we shall have occasion to use tentatively later.

The above figures, of course, all apply to the total rations of the several periods, the experiment affording no sufficient data for computing separately the metabolizable energy of the hay and of the linseed meal. We can, however, make an approximate computation by difference. The amount of linseed meal fed having been the same for the several periods, if we take the ration of Period A as a basal ration and subtract the results from those in the other periods, the difference will represent the effect of the added hay. In so doing, however, we virtually ascribe all the difference in the digestibility of the hay in the several periods to the relatively small amount added, and as a natural result the percentage of energy metabolized appears to diminish rapidly, as appears in the table on the next page.

Computed metabolizable energy of hay.

Period.	Gross energy.		Metabolizable energy.	Percentage metabolizable.	
	Total.	Of digested matter.		Of total energy.	Of energy of digested matter.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Per cent.</i>	<i>Per cent.</i>
B.....	20,274	11,700	9,491	.....	.....
A.....	14,859	8,427	6,651	.....	.....
Difference.....	5,415	3,273	2,840	52.45	86.77
C.....	25,135	13,679	11,198	.....	.....
A.....	14,859	8,427	6,651	.....	.....
Difference.....	10,276	5,252	4,547	44.25	85.58
D.....	29,538	15,295	12,106	.....	.....
A.....	14,859	8,427	6,651	.....	.....
Difference.....	14,679	6,868	5,455	37.16	79.42

The computation upon the energy of the digested matter, as before, largely eliminates the differences between the several periods. The falling off in the last case in the table arises chiefly from an unusually large excretion of methane in Period D, as appears clearly in the following table, showing the distribution of the energy of the digested matter:

Distribution of energy of digested matter.

Period.	In urine.	In methane.	Metabolizable.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
A.....	9.40	11.68	78.92
B.....	8.17	10.71	81.12
C.....	8.09	10.04	81.87
D.....	8.45	12.41	79.14

As compared with Kellner's well-known results upon coarse fodders,^a these figures show that the percentage of the total (gross) energy of the hay which was metabolized was apparently somewhat less than was found by that investigator for meadow hay. On the other hand, when computed upon the digestible matter only, our percentage is somewhat greater than Kellner's, a result due in part to the somewhat smaller loss of energy in the urine.

NET AVAILABILITY.

Numerous experimenters have shown that when food is supplied to a previously fasting animal the metabolism and consequent heat production is usually increased. This increased heat production is commonly ascribed to an expenditure of energy in the processes of

^aLandw. Vers.-Stat., v. 53.

digestion, including mastication, and in the chemical changes incident to the conversion of the digested material into such forms as are fitted to sustain the physiological processes of the body. The energy thus expended has been briefly designated as the work of digestion and assimilation. This energy ultimately takes the form of heat, in which form it is of no direct use to the body, although it appears under some circumstances to be of indirect use in maintaining the body temperature and thus preventing the consumption of tissue for that purpose. It is obvious, then, that unless this compensation takes place the energy expended in digestion and assimilation is waste energy so far as relates to maintenance or production of body tissue, and that only that portion of the metabolizable energy of the food which remains after the work of digestion and assimilation has been accomplished is capable of serving the general physiological uses of the organism. The portion of the metabolizable energy remaining after deducting the work of digestion and assimilation has been designated as available energy, or, more specifically, as net available energy, to distinguish it from what has been called gross available energy, equivalent to the term metabolizable energy as here used.

It is obvious that if we can determine the metabolism of an animal in the fasting state and also after the consumption of a known amount of food, we can determine the available energy of the latter by subtracting from its metabolizable energy the increase in the heat production of the animal. In the case of ruminants, however, it is impracticable, for obvious reasons, to determine satisfactorily the fasting metabolism. The determination of the available energy of a feeding stuff, however, may be equally well, although a little less simply, made by adding the substance in question to a known basal ration and determining the increase of heat production or, what amounts to the same thing, the extent to which the added food diminishes the previous loss of tissue. In other words, the availability can be determined by a computation by difference between two rations less than the maintenance ration in substantially the same way that Kellner has employed to determine the production value above the maintenance ration. In the former case the difference in the loss of tissue on the two rations will represent the amount of available energy in the added food, since it shows the extent to which the latter has been able to take the place of tissue previously oxidized.

Such a comparison can, of course, be based either upon the total energy of the food, the energy of the digested matter, or upon the metabolizable energy. Since, however, the latter represents the amount of energy actually put at the disposal of the organism, it seems the proper basis upon which to make the comparison with a view to discovering the general laws governing availability, and this method has been followed.

As the balance of energy on page 45 shows, however, the gain or loss as computed from the nitrogen and carbon balance does not exactly agree with that computed from the difference between ingo and outcome of energy. For the present purpose it seems most satisfactory to use the average of these results or, in other words, to substitute in the balance of energy on page 45 the average of the computed and the observed heat production as given on page 47. Thus, in Period A, we obtain the following as the average loss of energy in the form of protein and fat:

Average loss of energy.

Feed, excreta, etc.	Income.	Outgo.
	<i>Calories.</i>	<i>Calories.</i>
Hay	13, 035	.....
Linseed meal.....	1, 824	.....
Feces.....		6, 432
Urine, corrected.....		853
Methane.....		984
Epithelial tissue.....		88
Average heat production.....		9, 229
Computed loss of protein and fat.....	2, 727	.....
Total	17, 586	17, 586

In making the comparison with the metabolizable energy, however, the loss of tissue as thus computed must be corrected by subtracting 7.45 Calories for each gram of nitrogen in the urine, since the amount of metabolizable energy was corrected in the same way. The average figures for the growth of epithelial tissue must also be counted as part of the gain. Making these corrections we have the following results for the several periods, those for Period C being computed both on the basis of the observed and of the computed heat production instead of upon the average, as in the other cases:

Average gain or loss.

Period.	Average gain or loss of protein and fat.	Growth of epithelial tissue.	Correction for nitrogen.	Total gain or loss.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>
A	-2, 727	+88	+61	-2, 578
B	- 855	+88	+ 9	- 758
C, based on observed heat production	+ 358	+88	+ 3	+ 449
C, based on computed heat production	- 9	+88	+ 3	+ 82
C (average)				+ 266
D	+ 566	+88	-83	+ 571

From the computed heat production standing and lying we can compute in the same way the gain or loss of tissue in the two positions.

Since, however, we have no determinations of the carbon and nitrogen balance in the two positions of the animal these computations must, of course, be based upon the heat production as directly measured. If, then, we substitute in the balance of energy as given on page 45 the computed heat production lying and standing, respectively, upon the two hypotheses indicated above—that is, if we compute the gain or loss of energy by difference—we obtain the following figures for the gain:

Computed gain lying and standing.

Period.	Gain of protein and fat.		Growth of epithelial tissue.	Correction for nitrogen.	Total gain.	
	First hypothesis.	Second hypothesis.			First hypothesis.	Second hypothesis.
LYING.	Calories.	Calories.	Calories.	Calories.	Calories.	Calories.
A	-1,418	-1,748	+88	+61	-1,269	-1,599
B	+1,094	+ 624	+88	+ 9	+1,191	+ 721
C	+2,002	+1,596	+88	+ 3	+2,093	+1,687
D	+2,415	+1,983	+88	-83	+2,420	+1,988
STANDING.						
A	-3,676	-3,431	+88	+61	-3,527	-3,282
B	-1,841	-1,621	+88	+ 9	-1,744	-1,524
C	- 911	- 597	+88	+ 3	- 820	- 506
D	- 513	- 243	+88	-83	- 508	- 238

The observed and computed results of the experiment are presented graphically upon Diagram III, in which the abscissæ represent the amounts of metabolizable energy supplied to the animal and the ordinates the resulting gain or loss of energy. Represented in this way, the angle with the horizontal made by the straight line connecting any two points will increase or decrease as the availability of the food increases or decreases, becoming 45° when the latter equals 100 per cent. Thus, comparing Periods A and B, and regarding Period A as the basal period, the distance AE on the diagram represents the amount of metabolizable energy added to the basal ration in Period B, while EB represents the extent to which the loss of tissue has been diminished thereby; that is, it represents the available energy of the added food. The percentage availability, then, will obviously be equal to $\frac{BE}{AE} = \tan BAE$.

In like manner each period has been compared with the next lower. Thus, subtracting Period A from Period B, we find that 2,840 Calories of metabolizable energy were added in the latter period, and that they diminished the loss of tissue by 1,820 Calories. The percentage availability, therefore, is $\frac{1,820}{2,840} = 64.08$ per cent. The same computations for Periods C and D, and for the lying and standing positions upon the two hypotheses stated above, give the results contained in

the following tables. In the first table the average gains have been made the basis of the comparison, including in this Period C, in spite of the considerable discrepancy between the two determinations:

Availability of energy—observed results.

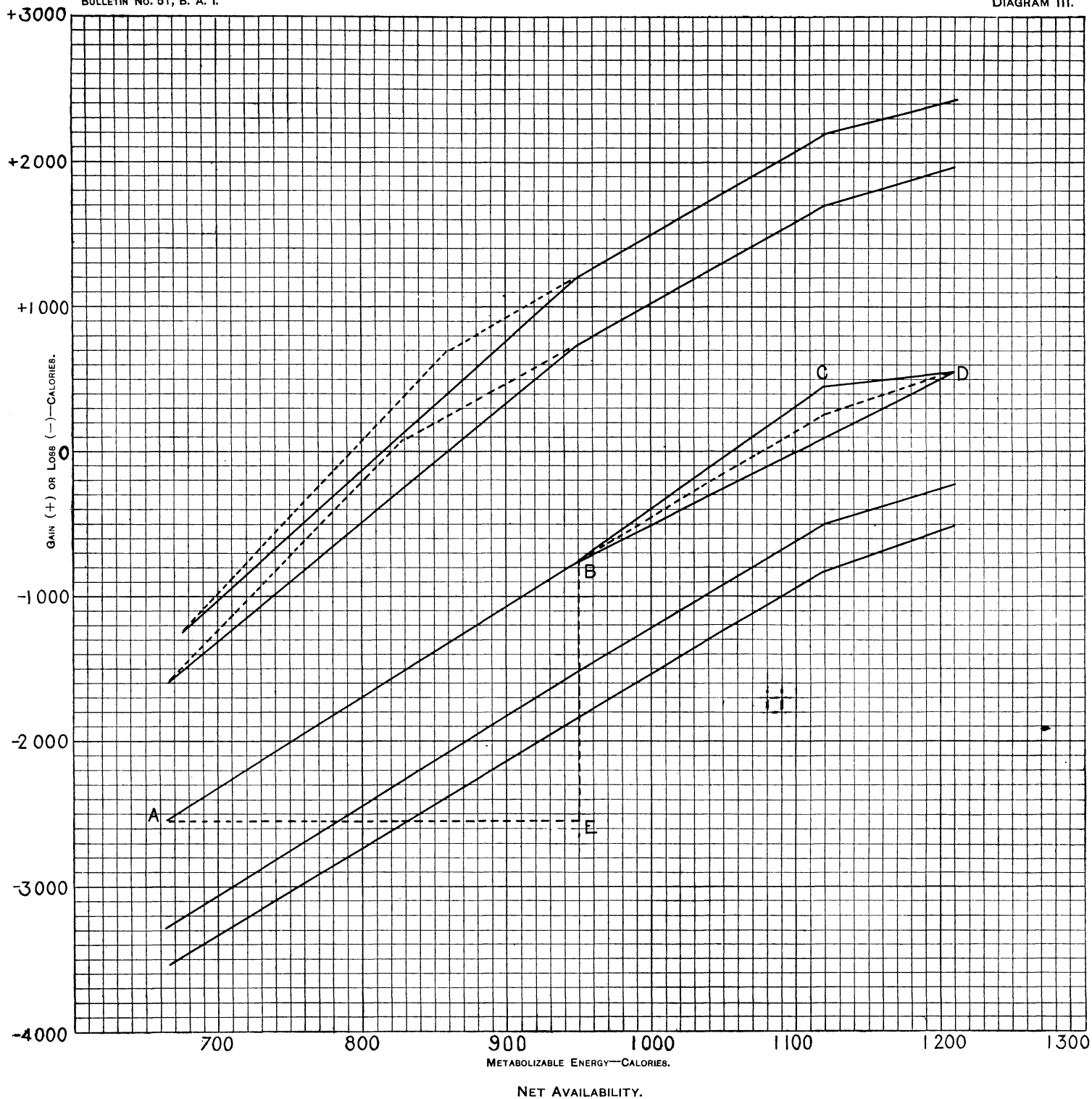
Period.	Metabolizable energy.	Gain.	Availability.
	<i>Calories.</i>	<i>Calories.</i>	<i>Per cent.</i>
B	9,491	— 758	.....
A	6,651	—2,578	.....
Difference	2,840	1,820	64.08
Ca	11,198	+ 266	.....
B	9,491	— 758	.....
Difference	1,707	1,024	59.99
D	12,106	+ 571	.....
Ca	11,198	+ 266	.....
Difference	908	305	33.59

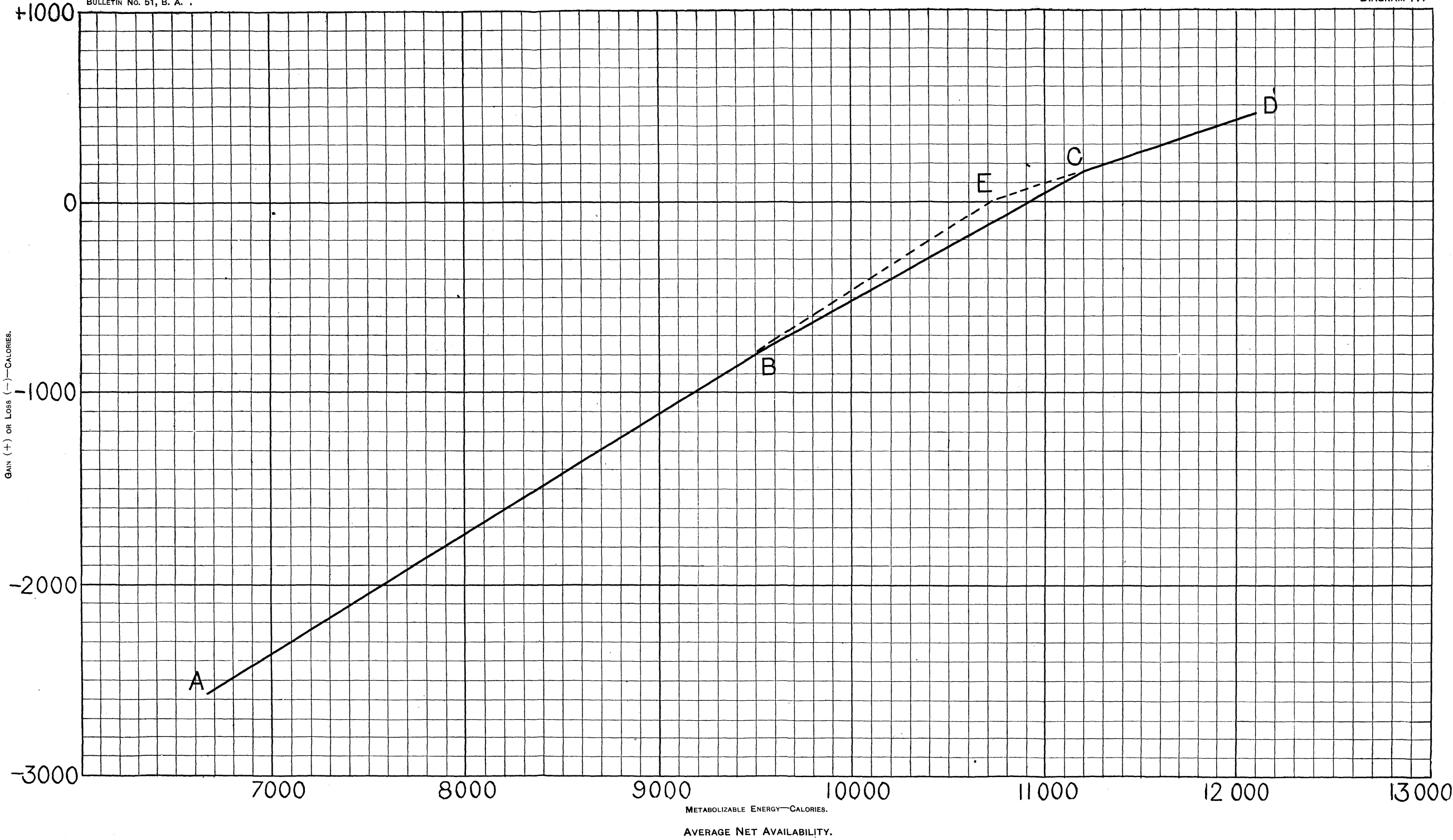
^a Using average gain; see p. 54.

Availability of energy—computed results.

Period.	Metabolizable energy.	First hypothesis.		Second hypothesis.	
		Gain.	Availability.	Gain.	Availability.
LYING.	<i>Calories.</i>	<i>Calories.</i>	<i>Per cent.</i>	<i>Calories.</i>	<i>Per cent.</i>
B	9,491	+1,191	.....	+ 721	.....
A	6,651	—1,269	.....	—1,599	.....
Difference	2,840	2,460	86.62	2,320	81.69
C	11,198	+2,093	.....	+1,687	.....
B	9,491	+1,191	.....	+ 721	.....
Difference	1,707	902	52.84	966	56.59
D	12,106	+2,420	.....	+1,988	.....
C	11,198	+2,093	.....	+1,687	.....
Difference	908	327	36.02	301	33.15
STANDING.					
B	9,491	—1,744	.....	—1,524	.....
A	6,651	—3,527	.....	—3,282	.....
Difference	2,840	1,783	62.78	1,758	61.90
C	11,198	— 820	.....	— 506	.....
B	9,491	—1,744	.....	—1,524	.....
Difference	1,707	924	54.13	1,018	59.64
D	12,106	— 508	.....	— 238	.....
C	11,198	— 820	.....	— 506	.....
Difference	908	312	34.37	268	29.52

Both the above tables and the diagram show a close general agreement with the exception of the computed results in Period B—A, lying.





We are inclined to explain this divergence by the supposition that when the animal was lying down in Period A the relatively small amount of heat arising from the digestion and assimilation of the very light ration, together with that produced by the necessary internal work of the animal, was insufficient to maintain the body temperature, and that consequently there was a direct stimulation to the processes of heat production, resulting in a greater loss of energy by the animal than corresponded to the availability of the energy of the hay.

It is evident both from the figures and the diagram that the two hypotheses as to the rate of excretion of the water vapor standing and lying affect the final results but very slightly.

Averaging the percentage availabilities by the above methods of computation, omitting those of Period B-A, lying, we have the following results:

Average availability of energy.

	Period B-A.	Period C-B.	Period D-C.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Observed	64.08	59.99	33.51
Computed, lying:			
First hypothesis	[86.62]	52.84	36.02
Second hypothesis	[81.69]	56.59	33.15
Computed, standing:			
First hypothesis	62.78	54.13	34.37
Second hypothesis	61.90	59.64	29.52
Average	62.92	56.64	33.31

As noted on page 47, it seems possible that the results for digestibility, and consequently for metabolizable energy, in Period A are somewhat too low. If we make the conjectural correction in the amount of metabolizable energy indicated on page 51, the results for Period B-A would be as follows:

	<i>Per cent.</i>
Observed	59.39
Computed lying:	
First hypothesis	84.87
Second hypothesis	79.30
Computed standing:	
First hypothesis	57.92
Second hypothesis	56.93

While the percentages computed in this way are somewhat lower than those calculated in the table, the differences are relatively small in themselves, and affect but very slightly the general teachings of the experiment.

During Periods A and B the results as observed show a loss of tissue by the animal, and the comparison between these two, therefore, shows

the extent to which this loss was diminished by means of hay added to the ration. In Periods C and D, on the other hand, there was a gain by the animal, and the comparison between these two periods shows the extent to which the gain was increased by the addition of hay.

The results as computed standing are all below the maintenance requirement, while of those computed lying all but one are above the maintenance requirement. It seems very doubtful, however, whether the gain which is computed to have taken place while the animal was lying down represents any real formation of new tissue; that is, whether the storage of energy which appears to have taken place in these short periods is to be interpreted as an actual formation of proteid tissue and fat. It seems more probable that it was, at least largely, simply a storing up of assimilated material which was used up again as fuel when the animal stood. In other words, it seems probable that it was the amount rather than the nature of the metabolism which was affected by the position of the animal, and this view is confirmed by the general similarity of all the lines upon the diagram and of the percentages as calculated in the preceding table. Granting this, the average percentages computed in the last table may fairly be taken to represent approximately the percentage availability of the successive additions of hay.

If we take the observed results in Period A as a starting point and multiply the successive increments of metabolizable energy by the average percentages just computed, we get the figures of the following table, which may be taken as representing the average of the results of the experiment as variously computed. The same results are represented graphically in Diagram IV:

Values for energy—average results.

Period.	Metabolizable energy.	Average availability.	Computed available and gain.
	<i>Calories.</i>	<i>Per cent.</i>	<i>Calories.</i>
B	9,491	.....	— 791
A	6,651	.....	— 2,578
Difference	2,840	62.92	1,777
C	11,198	.....	+ 176
B	9,491	.....	— 791
Difference	1,707	56.64	967
D	12,106	.....	+ 478
C	11,198	.....	+ 176
Difference	908	33.31	302

Comparing Periods A and B, we conclude, then, that the percentage availability of the metabolizable energy below the maintenance require-

ment was 62.92 per cent. Similarly, comparing Periods C and D above the maintenance requirement, we find that the percentage of metabolizable energy actually utilized in the formation of tissue was 33.31 per cent.

If we assume the percentage availability below maintenance and the percentage utilization above maintenance to be linear functions of the metabolizable energy, then the result obtained by comparing Periods C and D is a mixed result. In other words, the line *AB* in Diagram IV, on this hypothesis, would continue in the same direction until it intersected the zero line, from which point it would continue through *C* and *D*, making an angle with its previous course. In other words the lines *AB* and *DC* in the diagram, if produced, should intersect the zero line at the same point, and this point would indicate the maintenance requirement of the animal. We can readily compute these points of intersection as follows: Dividing the loss in Period B, 2,578 Calories, by the percentage availability, 0.6292, we have 4,097 Calories as the amount of metabolizable energy required to be added to the basal ration to exactly balance this loss. Adding to this the 6,651 Calories of the basal ration, we have a total of 10,748 Calories as the maintenance requirement. A precisely similar computation may be made from the figures of Periods C and D. The results in the two cases may be concisely tabulated as follows:

Computed maintenance requirement.

From Periods A and B.	$\left\{ \begin{array}{l} 2,578 \text{ Calories} \div 0.6292 = 4,097 \text{ Calories.} \\ 4,097 \text{ Calories} + 6,651 \text{ Calories} = 10,748 \text{ Calories.} \end{array} \right.$
From Periods C and D.	$\left\{ \begin{array}{l} 478 \text{ Calories} \div 0.3331 = 1,435 \text{ Calories.} \\ 12,106 \text{ Calories} - 1,435 \text{ Calories} = 10,671 \text{ Calories.} \end{array} \right.$

These figures show a very close agreement, and the same thing is shown also in the diagram by the production of the lines *AB* and *DC*, both of them intersecting the zero line at approximately the same point, *E*. We may fairly conclude, then, that the line *AED* in the diagram represents the law of availability in these experiments.

Strictly speaking, all the above results are subject to a correction for the varying live weight of the animal. The actual weights on the respiration days did not differ very widely, however, while we have very meager data as to the actual effect of such differences upon the metabolism. The correction would be relatively small in any case and we have thought it on the whole most satisfactory to omit it altogether.

The above results upon availability, like those upon metabolizable energy, may also be brought into relation to the total or the digestible organic matter of the feed. Taking the results for metabolizable energy per gram of organic matter, tabulated on page 50, we have simply to multiply by 0.6292 or 0.3331 to obtain, respectively, the cor-

responding amounts of net available energy or of energy stored as gain, as follows:

Net available energy.

Period.	Per gram of total organic matter.			Per gram of digestible organic matter.		
	Metabolizable energy.	Available energy.	Energy utilized for gain.	Metabolizable energy.	Available energy.	Energy stored as gain.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calorie.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>
A.....	2.156	1.357	0.718	3.633	2.287	1.210
B.....	2.275	1.432	.758	3.736	2.352	1.245
C.....	2.143	1.348	.714	3.716	2.339	1.238
D.....	1.972	1.241	.657	3.592	2.261	1.197

Kellner^a found for two samples of meadow hay an average utilization of 41.5 per cent of the metabolizable energy and 37.6 per cent for that of one sample of oat straw. The corresponding figures per gram of organic matter, computed in a slightly different manner, were:

Net available energy of meadow hay and oat straw.

	Meadow hay.	Oat straw.
	<i>Calories.</i>	<i>Calories.</i>
Per gram total organic matter.....	0.950	0.623
Per gram digestible organic matter.....	1.510	1.409

The lower figures obtained by us for timothy hay may well be ascribed to its coarser and more woody character, although, as already noted, the results are of somewhat questionable value on account of the small excess above maintenance which was consumed.

SUMMARY.

We are far from regarding the results of the experiment described in the foregoing pages as sufficiently extensive to warrant positive conclusions. On the contrary, we present them and trust that they will be regarded as simply a report of progress, and we hope to be able to check them by more extensive investigations in the future. At the same time they relate to phases of the subject which have not heretofore, so far as we are aware, been the subject of specific investigation, and we therefore feel justified in considering somewhat more fully than might otherwise be proper the indications afforded by our results, with the express statement, however, that we regard such discussion as tentative only.

ISODYNAMIC REPLACEMENT.

Rubner's well-known experiments with dogs and other animals showed that at or below the maintenance requirement nearly pure nutrients

^a Landw. Vers. Stat., v. 53, p. 460.

could be substituted in the metabolism of the animal for the ingredients of body tissue, and that they were valuable for this purpose approximately in proportion to their metabolizable energy as above defined. For example, Rubner found that when nearly pure proteids were given to a fasting dog the amount of proteids destroyed in the body was largely increased, but that a correspondingly smaller amount of fat was oxidized, and, further, that the proteids replaced fat in inverse proportion to their content of metabolizable energy. Under these conditions there was of course no increase in the total amount of heat produced in the body, but simply a substitution of one kind of fuel for another. Rubner experimented with fats and carbohydrates as well as with proteids and found the same law to hold, while in a single experiment he also substituted carbohydrates for fats in the food in a corresponding ratio. This substitution of nutrients in the manner just indicated is called by Rubner "isodynamic replacement" and the relative values of the nutrients as deduced from it "isodynamic values." Rubner experimented chiefly with carnivora, but his law has been generally assumed to apply to all animals. Thus Kellner,^a in his extensive investigations upon cattle, regards the results which he obtained for the metabolizable energy of various materials as representing their value as part of the maintenance ration and speaks of them as "replacement values" (Vertretungswerte).

As has already been indicated, however, it has been well established by the investigations of Zuntz and others that there is a not inconsiderable expenditure of energy in the digestion and assimilation of the food. This energy must ultimately assume the form of heat in the body, the amount of heat produced depending on the kind and amount of food consumed. This would seem to imply an increase in the heat production with increasing quantities of food, and therefore to contradict the law of isodynamic replacement. Rubner explains this apparent discrepancy by the hypothesis that the heat into which the energy expended in digestion and assimilation is ultimately converted is substituted in the body for an equivalent amount of heat which would otherwise be produced by oxidation of body substance in order to maintain the temperature of the body, so that there is no increase in the total heat production.

Rubner's conclusions have exerted a profound influence upon the science of nutrition, but at the same time their value lies quite as much in the point of view which they opened up as in their exact numerical accuracy. As just stated, isodynamic replacement implies that there is no increase in heat production with an increasing amount of food. As a matter of fact, however, the great majority of Rubner's experiments do show more or less increase in the heat production, the only exceptions being a single experiment with fat and three or four

^aLandw. Vers. Stat., v. 53, pp. 448-449.

upon cane sugar, some of which Rubner himself considers of doubtful value. From theoretical considerations we had been led to question the entire applicability of Rubner's law to herbivorous animals, and especially to ruminants with their large expenditure of energy in digestive work, and the experiment here reported was planned to test the equivalence of the metabolizable energy of hay and that of body tissue.

The results obtained in the periods below the maintenance ration, as above reported, fully confirm this doubt. Only 63 per cent of the metabolizable energy served to prevent loss of tissue, while 37 per cent simply increased the heat production of the animal. In other words, *the digested matter of the hay was not isodynamic with body tissue under the conditions of this experiment.* Moreover, the difference is altogether too large to be ascribed to any experimental error or to be accounted for by the discrepancies in some of the results.

This difference may be reasonably ascribed to the relatively large expenditure of energy necessary in the digestion and assimilation of the hay. Even upon a comparatively light ration, this amount, in addition to the heat arising from the internal work of the body, appears to have been sufficient to maintain the normal body temperature at the comparatively high stable temperature (18.2° C.). Such being the case, when more hay was added the heat arising from its digestion and assimilation was in excess of the needs of the animal for heat and became an excretum, passing off without being of any direct service to the organism. In other words, what one of us has elsewhere designated^a as the critical amount of food must be relatively small in the case of a material like timothy hay, which requires a large amount of digestive work. In our experiment, even the smallest amount of food seems to have been in excess of the critical amount; consequently, when more food was added the additional heat resulting from its digestion and assimilation could not be used indirectly and served simply to increase the heat production, while only the remaining 63 per cent of the metabolizable energy served as fuel for the body in place of the tissue previously consumed.

Quite recently Rubner^b has published in book form an elaborate discussion of this question, including the results of later experiments on dogs in which amounts of fat, carbohydrates, or proteids considerably in excess of those required for the simple maintenance of the body were fed. Under these conditions, and at relatively high temperatures, he finds that all these nutrients, but especially the proteids, may cause a marked increase in the heat production of the animal. In other words, he shows that what appears to be true of ruminants below the maintenance requirement is equally true of carnivora when the amount of food consumed is relatively large. It is obvious that

^a Armsby: Principles of Animal Nutrition, p. 408.

^b Die Gesetze des Energieverbrauchs bei der Ernährung.

this result is entirely in harmony with our own, the only difference being that the critical amount of food appears to be relatively much larger with carnivora than with herbivora.

As already indicated, we are inclined to regard the results obtained in Period A, while the steer was lying down, as an exception to the above statements. Here we suspect the line indicating the availability of the metabolizable energy to be that indicated by the dotted lines in Diagram III. In other words, we believe that under these conditions isodynamic replacement would take place up to an amount of about 8,450 Calories of metabolizable energy, this constituting the critical amount of food when the animal was lying.

THE MAINTENANCE REQUIREMENT.

If the above conclusions are admitted, it is evident that the maintenance requirement of cattle is a question of tissue replacement rather than of heat production, and, therefore, that the value of a given feeding stuff for maintenance depends upon the availability of its energy. We may, for instance, regard it as at least very probable that the work of digestion and assimilation in the case of a material like corn meal would be materially less than in the case of hay; or, in other words, that a larger percentage of its energy would be available for the maintenance of tissue. It would follow from this that in case of a ration consisting largely of grain a less amount of material or of metabolizable energy would be required for maintenance than in the case of a ration consisting exclusively of coarse fodder. In other words, the maintenance ration is a variable rather than a constant, depending upon the kind of food used. It may be noted that this conclusion has already been indicated by the experiments upon the maintenance ration of cattle made at this station in 1896-97.^a

The average maintenance requirement of our animal as computed above is 10,710 Calories. The average weight of the animal during the experiment was approximately 410 kilograms. Computing to 500 kilograms live weight on the assumption that the maintenance requirement is proportional to the two-thirds power of the live weight, this equals 12,197 Calories. Kellner's average for coarse fodders is 11,520 Calories.^b As has just been pointed out, however, the amount of metabolizable energy required for maintenance varies with the availability of that energy. The availability of timothy hay is probably less than that of Kellner's meadow hay. Certainly the percentage utilization above maintenance as well as the percentage digestibility of the hay is less than that of Kellner's, as the above figures show. Naturally, therefore, more of it would be needed to reach the maintenance requirement.

^a Penn. Experiment Station Bul. No. 42, p. 159.

^b Loc. cit., p. 13.

INFLUENCE OF EXTERNAL TEMPERATURE ON THE MAINTENANCE REQUIREMENT.

If the heat production upon the maintenance ration is in excess of the requirements of the animal, it seems unlikely that small variations in the stable temperature to which the animal is exposed will have the effect upon the maintenance requirement which is ordinarily attributed to them. Still less is this likely to be the case with fattening cattle, where the amount of food and the consequent heat production are largely in excess of the maintenance ration.

EXPENDITURE OF ENERGY IN TISSUE BUILDING.

Our results indicate that the proportion of the metabolizable energy of the food which was utilized, above the maintenance requirement, to produce gain was decidedly less than that used below the maintenance requirement to prevent loss of tissue. In other words, they indicate that the conversion of digested and assimilated matter into actual tissue (fat) requires a considerable expenditure of energy, amounting in this case to about 47 per cent of the available energy or 30 per cent of the metabolizable energy. This result is quite in accordance with what we should anticipate. The digested matter of the food of herbivora appears to be resorbed chiefly in the form of carbohydrates and of organic acids. It seems altogether probable that a much less profound change is required to convert these resorbed products into forms suited to maintain the energy metabolism of the organism than is needed to convert them into the form of permanent tissue, especially fat. At the same time it should be noted that the amount of food given in excess of the maintenance requirement in this experiment was small and, moreover, that the results in Period C are somewhat doubtful. We do not feel, therefore, that very much stress should be laid upon the apparent results of this experiment in this particular.

INFLUENCE OF THE AMOUNT OF FOOD.

It has been commonly assumed that the percentage availability of the energy of a food, within reasonable limits, is unaffected by its amount, or, in other words, that the available energy is a linear function of the metabolizable energy. The plan of our experiments contemplated the feeding of three rations less than the maintenance ration. Unfortunately the results show that the ration of Period C was slightly in excess of the maintenance requirement and consequently we have only two points below that amount. The general agreement among themselves, however, of the results computed on the assumption that the availability is a linear function seems to afford considerable evidence in favor of this view, although it can not be said to demonstrate it, and the same may be said of the percentage utilization above maintenance so far as any conclusions can be drawn from the small gains observed.

We should anticipate that the muscular work of digestion would be approximately proportional to the dry matter supplied. As the figures show, the proportion of the total energy of the hay which was found to be metabolizable diminished as the amount was increased, the difference arising chiefly from differences in digestibility. Since, nevertheless, the total expenditure of energy in digestion and assimilation appears to be approximately proportional to the metabolizable energy, it seems evident that a large share of this expenditure must be for the work of assimilation. Probably a very large factor in it is the loss of energy in the methane fermentation.

COMPOSITION OF COMBUSTIBLE GASES.

The results upon the ratio of hydrogen to carbon in the combustible gases contained in the outgoing air current, as given on page 32, show that with this animal, under the conditions of this experiment, these gases consisted substantially of methane.

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APPENDIX.

TABLE I.—*Weight, water drunk, and excreta.*

For 24 hours ended on date given.	Live weight.	Water drunk.	Feces.	Urine. ^a	For 24 hours ended on date given.	Live weight.	Water drunk.	Feces.	Urine. ^a
HAY ONLY.					MIXED RATIONS.				
<i>Steer No. 1.</i>					<i>Steer No. 1.</i>				
Period A:					Period A:				
Dec., 1901.	<i>Kilos.</i>	<i>Kilos.</i>	<i>Grams.</i>	<i>Grams.</i>	Apr., 1902.	<i>Kilos.</i>	<i>Kilos.</i>	<i>Grams.</i>	<i>Grams.</i>
10.....	444.4	15.8	14,280	3,230	4.....	388.2	3.4	6,780	.....
11.....	448.0	18.0	13,380	3,460	5.....	382.5	13.8	6,335	3,298
12.....	448.0	14.0	14,520	3,700	6.....	385.0	9.2	6,640	2,760
13.....	444.4	17.0	12,860	4,240	7.....	384.8	11.2	5,875	2,605
14.....	442.0	21.4	14,670	<i>b</i> [3,220]	8.....	384.8	8.9	6,217	3,798
15.....	446.2	15.6	13,380	3,780	Total .....	.....	.....	45,112	20,706
16.....	444.0	17.0	14,500	3,490	2,spilled .....	.....	.....	64.1	554
17.....	443.4	17.6	15,020	<i>b</i> [1,570]	5,spilled .....	.....	.....	14.3	.....
18.....	444.0	15.4	11,710	3,840	Period B:				
19.....	444.0	18.0	13,080	<i>b</i> [3,490]	Feb., 1902.				
<i>Steer No. 2.</i>					23.....	414.8	15.4	.....	.....
Period A:					24.....	414.0	12.0	.....	.....
Dec., 1901.					25.....	411.4	14.0	.....	.....
10.....	442.6	0.4	9,890	3,000	26 ^d.....	.....	8.0	.....	.....
11.....	430.0	30.0	9,095	3,670	27.....	410.2	17.2	.....	.....
12.....	446.0	0.0	10,340	<i>b</i> [2,260]	28.....	412.4	0.0	.....	.....
13.....	429.2	34.2	10,260	5,740	Mar., 1902.				
14.....	448.8	0.0	10,330	4,410	1.....	399.6	22.8	.....	.....
15.....	432.8	27.4	9,850	4,100	2.....	410.4	10.4	.....	.....
16.....	445.2	0.0	11,150	3,620	3.....	406.7	8.8	.....	.....
17.....	433.0	23.0	9,550	4,060	4.....	404.4	11.6	.....	.....
18.....	442.9	0.0	14,650	2,970	5.....	.....	9.5	10,105	3,205
19.....	431.0	20.0	9,080	3,860	6.....	^e 407.3	10.6	6,800	2,637
MIXED RATIONS.					7.....	394.5	20.1	8,464	3,075
<i>Steer No. 1.</i>					8.....	403.2	9.6	9,192	2,614
Period A:					9.....	400.5	18.5	7,477	<i>f</i> 2,495
Mar., 1902.					10.....	407.3	6.6	9,825	2,980
26.....	418.0	0.9	.....	.....	11.....	402.5	18.2	7,842	2,690
27.....	405.2	22.4	.....	.....	Total .....	.....	.....	59,705	19,696
28.....	412.2	0.4	.....	.....	Spilled in calorimeter .....	.....	.....	565	.....
29.....	399.6	19.4	.....	.....	Period C:				
30.....	407.0	6.1	.....	.....	Mar., 1902.				
31.....	398.2	8.7	.....	.....	12.....	411.1	12.3	.....	.....
Apr., 1902.					13.....	410.3	19.2	.....	.....
1.....	396.8	10.8	.....	.....					
2.....	.....	1.9	6,090	3,660					
3.....	^c 396.8	16.6	7,175	4,585					

^aIncluding preservative and wash water.

^bSome loss. No sample taken.

^cWhen removed from calorimeter at 6 p. m.

^dIn calorimeter for preliminary test.

^eWhen removed from calorimeter at 6 p. m.

^fA very small quantity of urine lost.

TABLE I.—*Weight, water drunk, and excreta*—Continued.

For 24 hours ended on date given.	Live weight.	Water drunk.	Feces.	Urine. ^a	For 24 hours ended on date given.	Live weight.	Water drunk.	Feces.	Urine. ^a
MIXED RATIONS.					MIXED RATIONS.				
<i>Steer No. 1.</i>					<i>Steer No. 1.</i>				
Period C:					Period D:				
Mar., 1902.	<i>Kilos.</i>	<i>Kilos.</i>	<i>Grams.</i>	<i>Grams.</i>	Apr., 1902.	<i>Kilos.</i>	<i>Kilos.</i>	<i>Grams.</i>	<i>Grams.</i>
14.....	415.3	15.1	.....	.....	9.....	385.1	25.6	.....	.....
15.....	414.8	18.9	.....	.....	10.....	401.9	14.7	.....	.....
16.....	418.0	13.8	.....	.....	11.....	401.2	22.4	.....	.....
17.....	414.5	19.3	.....	.....	12.....	409.0	22.4	.....	.....
18.....	416.8	14.6	.....	.....	13.....	414.8	18.0	.....	.....
19.....	.....	15.3	13,075	3,441	14.....	413.5	23.7	.....	.....
20.....	^b 423.8	14.8	14,048	3,103	15.....	417.9	18.6	.....	.....
21.....	411.5	22.2	12,395	3,979	16.....	.....	20.1	17,520	4,675
22.....	416.5	12.5	13,378	3,825	17.....	^c 431.8	19.1	15,268	4,275
23.....	411.8	23.4	12,250	4,505	18.....	416.5	29.9	16,208	4,549
24.....	417.6	15.6	12,785	3,820	19.....	424.2	21.5	16,232	4,125
25.....	414.8	24.2	11,565	4,210	20.....	424.1	23.4	16,597	4,327
Total.....	.....	.....	89,496	26,883	21.....	425.2	19.8	17,413	4,365
Spilled in calorimeter.....	.....	.....	149	467.8	22.....	423.6	23.9	17,054	4,180
Spilled in stall.....	.....	.....	117.6	.....	Total.....	.....	.....	116,292	30,496
					Spilled in calorimeter.....	.....	.....	42.1	.....

^a Including preservative and wash water.^c On leaving calorimeter at 6 p. m.^b At 6 p. m. on leaving calorimeter.TABLE II.—*Composition of dry matter of feces.*

Constituents and energy.	Hay only.		Mixed rations.			
	Steer No. 1.	Steer No. 2.	Period A.	Period B.	Period C.	Period D.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Ash.....	5.97	5.97	6.25	6.19	6.07	6.15
Protein (N×6.25).....	7.26	7.08	7.57	7.47	7.26	7.11
Crude fiber.....	36.72	36.70	37.49	35.43	37.58	39.20
Nitrogen-free extract.....	46.94	47.14	46.23	48.06	46.48	44.92
Ether extract.....	3.11	3.11	2.46	2.85	2.61	2.62
	100.00	100.00	100.00	100.00	100.00	100.00
Total nitrogen.....	1.161	1.133	1.212	1.196	1.163	1.137
Proteid nitrogen.....	.....	.....	.914	1.033	1.016	.872
Pepsin-insoluble nitrogen.....	.....	.....	.985	.973	.973	.903
Carbon.....	.....	.....	48.585	49.330	48.682	48.460
	.....	.....	<i>Calories per gram.</i>	<i>Calories per gram.</i>	<i>Calories per gram.</i>	<i>Calories per gram.</i>
Heat of combustion.....	.....	.....	4.809	4.930	4.866	4.831

TABLE III.—*Digestibility of rations.*

Ration.	Dry mater.	Ash.	Or- ganic mater.	Pro- teids.	Non- pro- teids.	Crude fiber.	N-free ex- tract.	Ether ex- tract.	Nitro- gen.	Car- bon.	Ener- gy.
HAY ONLY.											
Steer No. 1.	Gms.	Gms.	Gms.	Grams.		Gms.	Gms.	Gms.	Gms.	Grams.	Cals.
Hay	5,986.3	277.8	5,708.5	304.7		2,330.0	2,949.3	124.5	48.73	.....	27,262
Feces	2,579.0	154.0	2,425.0	187.2		947.0	1,210.6	80.2	29.94	.....	12,872
Digested	3,407.3	123.8	3,283.5	117.5		1,383.0	1,738.7	44.3	18.79	.....	14,390
Coefficients, p.ct.	56.92	44.56	57.52	38.56		59.35	58.95	35.58	38.56	.....	52.78
Steer No. 2.											
Hay	4,788.9	222.2	4,566.7	243.7		1,863.8	2,359.6	99.6	38.98	.....	21,809
Feces	2,078.7	124.1	1,954.6	147.2		762.8	979.9	64.7	23.55	.....	10,231
Digested	2,710.2	98.1	2,612.1	96.5		1,101.0	1,379.7	34.9	15.43	.....	11,578
Coefficients, p.ct.	56.60	44.15	57.20	39.62		59.07	58.46	35.04	39.62	.....	53.09
MIXED RATIONS.											
Steer No. 1 only.											
Period A:											
Hay	2,879.5	133.3	2,746.2	136.5	7.5	1,112.1	1,427.6	62.5	23.4	1,337.6	13,035
Linseed meal....	357.8	19.1	338.7	111.5	8.8	31.9	149.9	36.6	22.2	172.5	1,824
Total	3,237.3	152.4	3,084.9	248.0	16.3	1,144.0	1,577.5	99.1	45.6	1,510.1	14,859
Feces	1,337.4	83.6	1,253.8	101.2	.....	501.4	618.3	32.9	16.2	649.8	6,432
Digested	1,899.9	68.8	1,831.1	146.8	16.3	642.6	959.2	66.2	29.4	860.3	8,427
Coefficients, p.ct.	58.69	45.14	59.36	59.19	100.00	56.17	60.80	66.80	.....	.....	56.71
Period B:											
Hay	4,018.0	182.8	3,835.2	192.5	8.0	1,546.9	1,995.8	92.0	32.5	1,876.8	18,463
Linseed meal....	354.7	18.7	336.0	110.6	9.2	30.8	149.3	36.1	22.1	170.7	1,811
Total	4,372.7	201.5	4,171.2	303.1	17.2	1,577.7	2,145.1	128.1	54.6	2,047.5	20,274
Feces	1,739.1	107.6	1,631.5	129.9	.....	616.2	835.8	49.6	20.8	858.0	8,574
Digested	2,633.6	93.9	2,539.7	173.2	17.2	961.5	1,309.3	78.5	33.8	1,189.5	11,700
Coefficients, p.ct.	60.23	46.60	60.89	57.15	100.00	60.94	61.04	61.28	.....	.....	57.76
Period C:											
Hay	5,124.3	235.7	4,888.6	241.9	8.7	1,972.8	2,554.0	111.2	40.6	2,366.9	23,321
Linseed meal....	356.1	19.3	336.8	108.8	9.2	32.9	150.0	35.9	21.8	172.5	1,814
Total	5,480.4	255.0	5,225.4	350.7	17.9	2,005.7	2,704.0	147.1	62.4	2,539.4	25,135
Feces	2,354.3	142.9	2,211.4	170.9	.....	884.7	1,094.3	61.5	27.4	1,146.1	11,456
Digested	3,126.1	112.1	3,014.0	179.8	17.9	1,121.0	1,609.7	85.6	35.0	1,393.3	13,679
Coefficients, p.ct.	57.05	43.96	57.68	51.27	100.00	55.89	59.53	58.19	.....	.....	54.42
Period D:											
Hay	6,085.8	284.2	5,801.6	326.8	19.5	2,361.9	2,937.0	156.4	56.4	2,831.7	27,727
Linseed meal....	354.4	19.0	335.4	107.6	11.1	32.6	147.6	36.5	21.9	172.6	1,811
Total	6,440.2	303.2	6,137.0	434.4	30.6	2,394.5	3,084.6	192.9	78.3	3,004.3	29,538
Feces	2,948.3	181.3	2,767.0	209.6	.....	1,155.7	1,324.4	77.3	33.5	1,428.7	14,243
Digested	3,491.9	121.9	3,370.0	224.8	30.6	1,238.8	1,760.2	115.6	44.8	1,575.6	15,295
Coefficients, p.ct.	54.22	40.22	54.92	51.75	100.00	51.74	57.06	59.93	.....	.....	51.78

TABLE IV.—*Results on urine.*

Period.	Weight.	Average specific gravity.	Total nitrogen.		Total carbon.		Energy.	
							Per gram.	Total.
	<i>Grams.</i>		<i>Per ct.</i>	<i>Grams.</i>	<i>Per ct.</i>	<i>Grams.</i>	<i>Calories.</i>	<i>Calories.</i>
Period A:								
Total collected	20,706	1.0366	1.047	216.79	2.540	525.9	0.2457	5,087
Spilled in calorimeter	554		.207	1.15	a.502	2.8	a.0486	27
Total	21,260			217.94		528.7		5,114
Daily average (6 days)	3,543			36.32		88.1		853
Period B:								
Total collected	19,696	1.0463	1.197	235.86	3.60	709.1	.3430	6,756
Daily average (7 days)	2,814			33.69		101.3		965
Period C:								
Total collected	26,883	1.0417	.879	236.30	3.03	814.6	.2860	7,689
Spilled	468		.535	2.50	a1.84	8.6	a.1741	81
Total	27,351			238.80		823.2		7,770
Daily average (7 days)	3,907			34.11		117.6		1,110
Period D:								
Total collected	30,496	1.0396	.744	226.89	2.85	869.1	.2778	8,472
Daily average (7 days)	4,357			32.41		124.2		1,210

Assumed to be proportional to nitrogen content.

TABLE V.—*Residual air.*

Period.	Aspirator reading, α	Barometer.	Temperature.	Weight of—		Corresponding volume at 0° and 760 mm.		Total volume of sample reduced.		Volume of moist air in chamber reduced.	Total in chamber of—	
				Water.	Carbon dioxide.	Water.	Carbon dioxide.	Dry.	As sampled.		Water.	Carbon dioxide.
<i>Period A.</i>	<i>Liters</i>	<i>Mm.</i>	<i>°C.</i>	<i>Gms.</i>	<i>Gms.</i>	<i>Liters</i>	<i>Liters</i>	<i>Liters</i>	<i>Liters</i>	<i>Liters</i>	<i>Gms.</i>	<i>Gms.</i>
At beginning of subperiod 1.	25	719.8	18.0	0.0878	b 0.16	0.04	21.77	21.93	10,888	.....	43.6	
At beginning of subperiod 2.	25	719.8	18.0	0.1329	.0901	.16	.04	21.77	21.93	10,888	66.0	44.7
At beginning of subperiod 3.	25	721.8	18.0	.1175	.0944	.15	.04	21.84	21.99	10,918	58.3	46.9
At beginning of subperiod 4.	25	725.7	18.5	.1088	.0907	.14	.04	21.90	22.04	10,977	54.2	45.2
At end of subperiod 4	25	727.5	19.1	.1635	.0974	.20	.05	21.91	22.11	11,004	81.4	48.5
<i>Period B.</i>												
At beginning of subperiod 1.	25	727.4	17.8	.1605	.0995	.19	.05	22.04	22.23	11,008	79.5	49.3
At beginning of subperiod 3.	25	720.9	17.7	.1550	.1043	.19	.05	21.85	22.04	10,677	75.1	50.5
At end of subperiod 4	25	732.7	17.9	.1338	.1116	.16	.05	22.15	22.31	10,604	63.7	53.1
<i>Period C.</i>												
At beginning of subperiod 1.	25	734.0	17.0	.1131	.1262	.14	.07	22.35	22.49	11,102	55.8	62.3
At beginning of subperiod 2.	25	733.9	16.4	.1349	.1050	.16	.05	22.40	22.56	11,101	66.3	51.7
At beginning of subperiod 3.	25	725.6	17.0	.1277	.1124	.16	.06	22.08	22.24	10,930	62.8	55.2
At beginning of subperiod 4.	25	726.5	18.2	.1470	.1132	.19	.06	21.98	22.17	10,990	72.9	56.1
At end of subperiod 4	25	727.6	15.4	.1715	.1044	.21	.05	22.26	22.47	11,007	84.0	51.1
<i>Period D.</i>												
At beginning of subperiod 1.	25	731.5	19.5	.1593	.1235	.20	.06	22.00	22.20	11,065	79.4	61.6
At beginning of subperiod 2.	25	731.6	17.8	.1515	.1231	.18	.06	22.18	22.36	11,066	75.0	60.9
At beginning of subperiod 3.	25	727.5	20.1	.1297	.1282	.16	.06	19.57	19.73	11,004	72.3	71.5
At beginning of subperiod 4.	25	726.6	17.8	.1543	.1170	.18	.06	22.07	22.25	10,991	76.2	57.8
At end of subperiod 4	25	725.3	19.4	.1266	.1171	.16	.06	21.88	22.04	10,971	63.0	58.3

 α Assumed to be saturated with aqueous vapor.

b Assumed correction.

TABLE VI.—*Ventilation.*

Period.	Volume at meter pump.	Average barometer.	Average tension of aqueous vapor.	Average temperature.	Reduced volume at meter pump, dry.	Sample for residual air, dry.	Methane produced.	Volume of entering air, dry.
<i>Period A.</i>	<i>Liters.</i>	<i>mm.</i>	<i>mm.</i>	<i>° C.</i>	<i>Liters.</i>	<i>Liters.</i>	<i>Liters.</i>	<i>Liters.</i>
Subperiod 1	480,350	719.8	1.75	14.77	430,542.5	10.9	[52.1]	430,501.3
Subperiod 2	488,400	721.8	1.29	15.1	438,754.4	21.8	52.7	438,723.5
Subperiod 3	488,000	725.5	1.15	15.0	440,896.7	21.9	52.9	440,865.7
Subperiod 4	488,000	727.2	1.17	16.2	440,073.4	32.9	50.7	440,055.6
<i>Period B.</i>								
Subperiod 1	468,100	727.4	1.36	13.4	426,358.6	11.0	61.7	426,307.9
Subperiod 2	471,800	720.9	1.35	14.0	424,881.6	10.9	64.8	424,827.7
Subperiod 3	479,400	724.1	1.34	13.9	433,920.1	10.9	73.4	433,857.6
Subperiod 4	488,000	730.4	1.20	15.0	443,812.8	11.1	63.9	443,759.4
<i>Period C.</i>								
Subperiod 1	483,600	734.0	1.31	13.6	444,105.4	33.5	66.1	444,072.8
Subperiod 2	492,200	728.3	1.11	14.2	447,697.6	22.2	73.0	447,646.9
Subperiod 3	489,600	726.8	1.21	15.3	442,607.9	22.0	78.7	442,551.2
Subperiod 4	487,350	727.7	1.11	15.0	441,711.2	19.7	72.0	441,672.5
<i>Period D.</i>								
Subperiod 1	483,200	731.6	1.75	15.8	438,613.8	19.57	99.3	438,536.8
Subperiod 2	485,100	729.7	1.74	16.2	442,750.6	19.57	96.9	442,673.3
Subperiod 3	484,500	727.0	1.93	16.5	435,887.3	22.07	102.4	435,807.0
Subperiod 4	483,450	726.6	1.74	16.8	434,459.5	21.9	101.2	434,380.2

TABLE VII.—*Ingoing air.*

Period.	Aspirator reading.	Barometer.	Temperature.	Reduced aspirator reading dry.	Volume of carbon dioxide.	Total volume of sample, reduced and dry.	Ratio of sample to total ventilation.	Water.		Carbon dioxide.	
								In sample.	In total ventilation.	In sample.	In total ventilation.
<i>Period A.</i>	<i>Liters.</i>	<i>mm.</i>	<i>° C.</i>	<i>Liters.</i>	<i>Liter.</i>	<i>Liters.</i>	<i>1:</i>	<i>Gram.</i>	<i>Grams.</i>	<i>Gram.</i>	<i>Grams.</i>
Subperiod 1	200	719.8	19.8	172.88	.05	172.94	2,489.5	0.3155	785.5	0.1145	285.1
Subperiod 2	200	721.8	19.5	173.55	.05	173.60	2,527.5	.1760	444.9	.1095	276.8
Subperiod 3	200	725.5	20.0	174.31	.05	174.36	2,528.5	.2330	589.1	.1080	273.1
Subperiod 4	200	727.5	20.8	174.13	.05	174.18	2,526.5	.1450	366.3	.0975	246.3
<i>Period B.</i>											
Subperiod 1	200	726.0	18.2	175.73	.05	175.78	2,425.4	.5715	1,386.3	.1100	266.8
Subperiod 2	200	720.0	17.9	174.46	.07	174.53	2,434.2	.4220	1,027.2	.1375	334.7
Subperiod 3	200	728.0	17.4	177.15	.05	177.20	2,448.5	.1660	406.5	.1045	255.9
Subperiod 4	200	732.7	21.0	175.42	.04	175.46	2,529.1	.0655	165.7	.0965	244.1
<i>Period C.</i>											
Subperiod 1	200	733.9	19.0	177.00	.05	177.05	2,508.2	.2320	582.0	.1045	262.1
Subperiod 2	200	725.6	19.2	174.85	.05	174.9	2,559.4	.1965	502.9	.1015	259.8
Subperiod 3	200	726.5	20.2	174.47	.05	174.52	2,535.8	.2490	631.4	.1075	272.6
Subperiod 4	200	727.6	19.4	175.32	.05	175.37	2,518.5	.1915	482.3	.1045	263.2
<i>Period D.</i>											
Subperiod 1	200	731.6	20.2	175.35	.06	175.41	2,500.0	.3980	995.0	.1170	292.5
Subperiod 2	200	727.5	20.5	174.12	.05	174.17	2,541.6	.2680	681.2	.1035	263.1
Subperiod 3	200	726.6	19.4	174.88	.05	174.93	2,491.3	.1660	413.6	.1090	271.6
Subperiod 4	200	725.3	21.8	172.86	.05	172.91	2,512.2	.1015	255.0	.1050	263.8

TABLE VIII.—Carbon dioxide.

Period.	Carbon dioxide in samples (corrected). ^a		Total, Nos. 1 and 2 × 100.	In sample of residual air.	Correction for residual air.	Total CO ₂ in outcoming air.	Total CO ₂ in ingoing air.	CO ₂ added in chamber.	Equivalent carbon.
	Pan No. 1.	Pan No. 2.							
<i>Period A.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>	<i>Grams.</i>
Subperiod 1	9.799	9.724	1,952.4	0.05	+ 1.1	1,953.5	285.1	1,668.4	455.0
Subperiod 2	10.013	9.975	1,998.8	.09	+ 2.2	2,001.1	276.8	1,724.3	470.3
Subperiod 3	9.915	9.866	1,978.1	.09	— 1.7	1,976.5	273.1	1,703.4	464.5
Subperiod 4	9.935	10.033	1,996.8	.14	+ 3.3	2,000.2	246.3	1,753.9	478.3
<i>Period B.</i>									
Subperiod 1	11.345	11.328	2,267.3	.05	.....	2,267.4	266.8	2,000.6	545.6
Subperiod 2	11.160	11.117	2,227.7	.05	+ 1.22	2,229.0	334.7	1,894.3	516.6
Subperiod 3	11.471	11.525	2,299.6	.05	.....	2,299.7	255.9	2,043.8	557.4
Subperiod 4	10.924	10.985	2,190.9	.06	+ 2.6	2,193.5	244.1	1,949.4	531.6
<i>Period C.</i>									
Subperiod 1	12.574	12.483	2,505.7	.18	— 10.6	2,495.3	262.1	2,233.2	609.0
Subperiod 2	12.036	11.999	2,403.5	.11	+ 3.6	2,407.2	259.8	2,147.4	585.6
Subperiod 3	12.380	12.368	2,474.9	.11	+ .88	2,475.9	272.6	2,203.3	600.9
Subperiod 4	12.112	12.094	2,420.6	.16	— 5.0	2,415.8	263.2	2,152.6	587.1
<i>Period D.</i>									
Subperiod 1	13.312	13.318	2,663.0	.12	— .7	2,662.5	292.5	2,370.0	646.4
Subperiod 2	13.068	13.007	2,607.5	.13	+ 10.6	2,618.2	263.1	2,355.1	642.4
Subperiod 3	13.322	13.397	2,671.9	.12	— 13.7	2,658.3	271.6	2,386.7	651.0
Subperiod 4	13.081	13.028	2,610.9	.12	+ .5	2,611.6	263.8	2,347.8	640.4

^a For number of pump strokes, see page 30.

TABLE IX.—Water.

Period.	Water in samples (corrected). ^a		Total, Nos. 1 and 2 × 100.	In cans.	Drip water and absorbers.	In sample of residual air.	Correction for residual air.	Total H ₂ O in outcoming air + absorbers.	Total H ₂ O in ingoing air.	Water added in chamber.	Equivalent hydrogen.
	Pan No. 1.	Pan No. 2.									
<i>Period A.</i>	<i>Gms.</i>	<i>Gms.</i>	<i>Gms.</i>	<i>Grams.</i>	<i>Gms.</i>	<i>Gms.</i>	<i>Gms.</i>	<i>Grams.</i>	<i>Gms.</i>	<i>Grams.</i>	<i>Grams.</i>
Subperiod 1	4.233	4.229	846.2	1,755.0	0	0.07	.....	2,601.2	785.5	1,815.7	201.8
Subperiod 2	3.183	3.191	637.4	1,904.0	0	.13	— 7.7	2,533.8	444.9	2,088.9	232.1
Subperiod 3	2.829	2.824	565.3	2,066.0	0	.11	— 4.1	2,627.3	589.1	2,038.2	226.5
Subperiod 4	2.866	2.866	572.2	1,823.0	0	.22	+ 27.2	2,422.6	366.3	2,056.3	228.5
<i>Period B.</i>											
Subperiod 1	3.257	3.239	649.6	2,700.0	— 10	.08	.....	3,339.7	1,386.3	1,953.4	217.0
Subperiod 2	3.191	3.217	640.8	2,445.0	0	.08	— 4.42	3,081.4	1,027.2	2,054.2	228.3
Subperiod 3	2.696	2.759	545.5	2,088.0	0	.08	.....	2,633.5	406.5	2,227.0	247.5
Subperiod 4	2.921	2.944	586.5	1,618.0	0	.07	— 11.4	2,193.1	165.7	2,027.4	225.3
<i>Period C.</i>											
Subperiod 1	3.237	3.242	647.9	2,151.0	0	.18	+ 10.5	2,809.6	582.0	2,227.7	247.5
Subperiod 2	2.735	2.734	546.9	2,135.0	0	.13	— 3.6	2,678.5	502.9	2,175.6	241.7
Subperiod 3	2.975	2.971	594.6	2,292.0	0	.14	+ 10.1	2,896.9	631.4	2,265.5	251.7
Subperiod 4	2.711	2.711	542.2	2,305.0	0	.25	+ 11.1	2,858.6	482.3	2,376.3	264.0
<i>Period D.</i>											
Subperiod 1	4.280	4.238	851.8	2,444.0	0	.15	— 4.4	3,291.5	995.0	2,296.5	255.2
Subperiod 2	4.255	4.240	849.5	2,067.0	0	.13	— 2.6	2,914.0	681.2	2,232.8	248.1
Subperiod 3	4.702	4.705	940.7	1,946.0	0	.15	+ 3.9	2,890.7	413.6	2,477.1	275.2
Subperiod 4	4.237	4.226	846.3	1,774.0	0	.13	— 13.2	2,607.3	255.0	2,352.3	261.4

^a For number of pump strokes, see page 30.

TABLE XI.—*Heat measurements—Continued.*

[illegible]

TABLE XI.—*Heat measurements*—Continued.

Period.	Relative rate of flow.	Average temperature of water. current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total. heat, Calories at 20°.
		Ingoing.	Outcoming.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD C—Continued.											
Subperiod 2.											
6.15 a. m. to 9.30 a. m.	33	4.026	6.597	2.571	+0.009	2.580	453.00	1.0054	4.37	0.63	1,174.33
9.30 a. m. to 9.38 a. m.	32	4.010	6.305	2.295	+ .007	2.302	19.00	1.0055	3.75	.02	43.92
9.38 a. m. to 2.02 p. m.	31	4.131	7.093	2.962	+ .006	2.968	428.00	1.0053	3.12	.42	1,276.53
2.02 p. m. to 6.15 p. m.	33	4.437	7.097	2.660	+ .009	2.669	599.25	1.0052	4.37	.83	1,606.89
Latent heat of water vapor.....											4,101.67
Corrections for feed, etc.....											1,287.93
Total heat.....											+24.81
Subperiod 3.											
6.15 p. m. to 11.34 p. m.	33	3.972	6.330	2.358	+ .009	2.3668	753.00	1.0054	4.37	1.04	1,790.78
11.34 p. m. to 12.02 a. m.	32	3.923	6.189	2.266	+ .007	2.2727	57.00	1.0055	3.75	.07	130.17
12.02 a. m. to 4.02 a. m.	31	4.127	7.118	2.991	+ .006	2.9967	410.00	1.0052	3.12	.41	1,234.59
4.02 a. m. to 6.15 a. m.	33	4.038	6.944	2.906	+ .009	2.9154	314.00	1.0053	4.37	.44	919.96
Latent heat of water vapor.....											4,075.50
Corrections for feed, etc.....											1,341.15
Total heat.....											—6.38
Subperiod 4.											
6.15 a. m. to 8.10 a. m.	33	4.101	6.657	2.556	+ .009	2.5649	276.00	1.0054	4.37	.38	711.47
8.10 a. m. to 11.50 a. m.	31	4.515	7.474	2.959	+ .006	2.9653	350.00	1.0050	3.12	.35	1,043.65
11.50 a. m. to 12.06 p. m.	32	4.685	8.040	3.355	+ .007	3.3620	29.00	1.0048	3.75	.03	97.93
12.06 p. m. to 3.38 p. m.	33	4.634	7.223	2.589	+ .009	2.5975	511.00	1.0051	4.37	.71	1,333.29
3.38 p. m. to 6.15 p. m.	31	4.928	7.676	2.748	+ .006	2.7545	254.00	1.0049	3.12	.25	702.80
Latent heat of water vapor.....											3,889.14
Corrections for feed, etc.....											1,406.77
Total heat.....											+12.96
Total for period.....											5,308.87
Average per day.....											21,628.57
PERIOD D.											
Subperiod 1.											
6.00 p. m. to 7.22 p. m.	45	6.911	8.728	1.817	+ .024	1.841	300.00	1.0040	13.43	1.18	553.32
7.22 p. m. to 7.34 p. m.	43	6.853	8.713	1.860	+ .021	1.881	37.00	1.0040	12.17	.14	69.73
7.34 p. m. to 7.50 p. m.	45	6.825	8.645	1.820	+ .024	1.844	50.00	1.0041	13.43	.20	92.37
7.50 p. m. to 8.10 p. m.	47	6.786	8.548	1.762	+ .027	1.789	86.00	1.0041	14.60	.40	154.08
8.10 p. m. to 8.42 p. m.	50	5.380	7.491	2.111	+ .031	2.142	127.00	1.0048	16.36	.64	272.74
8.42 p. m. to 1.08 a. m.	45	5.279	6.795	1.516	+ .024	1.540	967.32	1.0050	13.43	3.81	1,492.99

TABLE XI.—*Heat measurements*—Continued.

Period.	Relative rate of flow.	Average temperature of water current.					Total water.	Average specific heat of water.	Heat produced in absorbers.		Total heat, Calories at 20°.
		Ingoing.	Outgoing.	Difference.	Correction for pressure.	Corrected difference.			Difference of pressure.	Equivalent heat.	
PERIOD D—Continued.											
<i>Subperiod L—Cont'd.</i>											
Latent heat of water vapor.....		°C.	°C.	°C.	°C.	°C.	Liters.		Cm.	Cals.	1,392.56
Corrections for feed, etc.....											+54.83
Total heat.....											5,720.48
Total for period.											23,058.88
Average per day.											11,529.44